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PB80-103153

# **Toward Classification and Rationale for Watershed Management and Stream Protection**

**Oregon State Univ, Corvallis Dept of Fisheries and Wildlife**

**Prepared for**

**Corvallis Environmental Research Lab, OR**

**Jun 79**

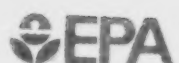
United States  
Environmental Protection  
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Environmental Research  
Laboratory  
Corvallis OR 97330

EPA-600/3-79-059  
June 1979

Research and Development

PB80-103153



# Toward Classification and Rationale for Watershed Management and Stream Protection

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# **TECHNICAL REPORT DATA**

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| 1. REPORT NO.<br>EPA-600/3-79-059                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                                                  | 3. RECIPIENT'S ACCESSION NO.<br>PB 80-103153   |  |
| 4. TITLE AND SUBTITLE<br>TOWARD CLASSIFICATION AND RATIONALE FOR WATERSHED<br>MANAGEMENT AND STREAM PROTECTION                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                                  | 5. REPORT DATE<br>June 1979 issuing date       |  |
| 7. AUTHOR(S)<br>Charles E. Warren                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                                                  | 6. PERFORMING ORGANIZATION CODE                |  |
| 9. PERFORMING ORGANIZATION NAME AND ADDRESS<br>Department of Fisheries and Wildlife<br>Oak Creek Laboratory of Biology<br>Oregon State University<br>Corvallis, Oregon 97331                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |                                                  | 8. PERFORMING ORGANIZATION REPORT NO.          |  |
| 12. SPONSORING AGENCY NAME AND ADDRESS<br>Corvallis Environmental Research Laboratory<br>Office of Research and Development<br>U. S. Environmental Protection Agency<br>200 SW 35th St., Corvallis, OR 97330                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |                                                  | 10. PROGRAM ELEMENT NO.                        |  |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |                                                  | 11. CONTRACT/GRANT NO.<br>Grant No. R805423    |  |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |                                                  | 13. TYPE OF REPORT AND PERIOD COVERED<br>final |  |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |                                                  | 14. SPONSORING AGENCY CODE<br>EPA/600/02       |  |
| 15. SUPPLEMENTARY NOTES                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                                                  |                                                |  |
| <p>16. ABSTRACT</p> <p>Classification can be used for increased understanding of systems and for improved relations of people with their environments. To be most useful, the classification must be applicable to a broad range of environmental conditions. This report offers a rationale for developing such a classification system for watershed management. A hierarchical classification is developed that is based on the potentials and environments of systems, especially on the capacities of watersheds and streams to remain in desirable states over relatively long times and to return to desirable states over relatively short times. The suggested approach is to classify headwater streams by using extant knowledge of biogeoclimatic regions, biogeoclimatic zones, watershed environments, stream order, and the morphological capacities of stream beds.</p> <p>It is argued that: (1) the rationales for watershed management must be available for public scrutiny and must include the proposed administrative institutions and practices together with procedures to correct these; (2) the management goals and objectives must be known, must enter the formulation of the classification at the outset, and must be based on societal goals and objectives; and (3) the possible levels of resource yield and quality that are expected with various management practices must be specified.</p> |                                                  |                                                |  |
| 17. KEY WORDS AND DOCUMENT ANALYSIS                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                                  |                                                |  |
| a. DESCRIPTORS                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | b. IDENTIFIERS/OPEN ENDED TERMS                  | c. COSATI Field/Group                          |  |
| Classification<br>Watershed<br>Community<br>Vegetation                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | Stream/Watershed System<br>Aquatic Community     | 08/H                                           |  |
| 18. DISTRIBUTION STATEMENT<br>Release unlimited                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | 19. SECURITY CLASS (This Report)<br>unclassified | 21. NO. OF PAGES<br>149                        |  |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | 20. SECURITY CLASS (This page)<br>unclassified   | 22. PRICE<br>PC A07<br>MFA01                   |  |

EPA-600/3-79-059  
June 1979

TOWARD CLASSIFICATION AND  
RATIONALE FOR WATERSHED MANAGEMENT  
AND STREAM PROTECTION

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Grant No. R805423

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## FOREWORD

Man and his environment must be protected from the adverse effects of pesticides, radiation, noise, and other forms of pollution, and the unwise management of solid waste. Efforts to protect the environment require a focus that recognizes the interplay between the components of our physical environment--air, water, and land. The Corvallis Environmental Research Laboratory contributes to this multidisciplinary focus through programs engaged in

- ° studies on the effects of environmental contaminants on the biosphere, and
- ° a search for ways to prevent contamination and to recycle valuable resources.

This report presents a rationale for developing a classification system for watershed management. Such an approach is useful for increasing our understanding of biophysical systems and for improving citizens' relationships with their environments.

James C. McCarty, Acting Director  
Corvallis Environmental Research  
Laboratory

## ABSTRACT

This report addresses the need and form of a rationale and a classification system for watershed management and stream protection. A clear distinction is made between the goals of environmental science--increased understanding--and the goals of environmental management--improved relations of man to his environment. Increased understanding of watershed systems will not alone insure intelligent management, because societal goals, needs, and mechanisms must also be taken into account.

A rationale for watershed management and stream protection should include: the conceptual framework upon which it is based; a set of resource and environmental management goals and objectives; a system of classification of the natural-cultural systems of concern; a set of criteria and a set of standards; administrative institutions, procedures and guidelines; procedures for monitoring and evaluating practices and outcomes; and a set of procedures indicating how institutions, standards, and practices are to be corrected as necessary to more nearly achieve management goals and objectives.

It is difficult if not impossible to conceive of a national program of watershed resource and environmental management that is not based on a very universal and hierarchical system of classification of biogeoclimatic regions, biogeoclimatic zones, watersheds, and stream systems. For such a classification to be universal--to be general and invariant--it should be based more on the capacities or potentials and the environments of the systems than on their states, which are usually too variant. The nature of a classification system is determined by objectives for it, by the conceptual framework or point of view taken, and by the nature of the objects or systems being classified.

Most of this report is devoted to the development of the form of a biogeoclimatic classification for watershed and stream systems. Scientific and management goals and objectives and the conceptual framework on which this form of classification is based are specified. And the problems of validation and application of the classification are considered in depth.

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#### ACKNOWLEDGMENT

Dr. Mostafa Shirazi, with patience and understanding, devoted many hours to discussion of the concepts entailed in this rationale and classification. And the staff and students of the Oak Creek Laboratory of Biology continued to be a source of support and inspiration.

## CONCLUSIONS

(1) The extent to which watershed systems can be so managed as to provide resources in needed amounts and yet be maintained in states otherwise generally acceptable is not clear. What is clear is that fundamental understanding of such natural-cultural systems, insofar as science can achieve this, and humanistic understanding to improve man's relations must be applied in a unified way. Upon this, the public should insist. The difficulty is that, from different perspectives, different judgments can be made as to the adequacy with which this is being done. For this reason, it is of the utmost importance that rationales for watershed management be explicitly and fully developed and made available for public scrutiny. Only in this way can watershed management be made rational, in the sense that it is at least made understandable. All too often, this is ignored in establishing public policy, and the effectiveness of that policy thereby suffers. Such a rationale should specify the conceptual framework--the point of view and assumptions--upon which it is based. Resource utilization and environmental goals and objectives must be consistently stated, for these are interrelated. Classification of the natural-cultural systems of concern is necessary for both the science and management of watersheds and should be made an integral part of any rationale. And it should include scientifically-based resource and environmental management criteria specifying the different levels of resource yield and environmental quality that would be expected to prevail were different management practices to be instituted. From these, on the basis of ecological, sociological, economic, and technological considerations, resource utilization and environmental practices and standards should be made clear. Administrative institutions, procedures, and guidelines for application and enforcement of practices and standards should be included in any rationale, as should procedures for monitoring and evaluating conformity and results. Finally, procedures for correcting institutions, standards, and practices, as dictated by experience, should also be included in a rationale for watershed management.

(2) All human social activities including science and management are based on overlapping conceptual frameworks of individual participants. Common backgrounds insure sufficient overlap of such frameworks for concordance of activities most of the time, even though the frameworks are rarely if ever made explicit or even recognized. But in matters where interests differ, there can be misunderstanding and real disagreement. Misunderstanding but not real disagreements can be avoided by specification of the principles and rules of whatever conceptual framework underlies an approach to science or management. Then, even with disagreement, at least rationality can be achieved, the bases of disagreements as well as agreements being set forth. A conceptual framework should, at a very

general and abstract level, make clear the underlying nature of natural-cultural systems. At the outset, any system of interest should be recognized as extending not only in space but also through time from its origin to its end, this being limited only for purposes of the sorts of explanation and understanding being sought. Coextensive with any system of interest is a codetermining environmental system. The capacity of the system, in some sense, provides for all possible performances or states of the system in all possible environments. Although capacity cannot be directly and completely evaluated, it is of more scientific and management interest than particular performances, in that it provides insight into what the system is capable of under different environmental conditions. Adapted systems tend toward concordance of their capacities as well as their performances with those of their environments. And systems tend to incorporate not only their subsystems but the level-specific environments of these subsystems. Such a view of natural-cultural systems--such a conceptual framework--when applied to problems of the science and management of watershed systems leads to approaches and results differing importantly from those deriving from other perspectives.

(3) Classification of objects and relations underlies all human perception, understanding, judgment, communication, and activity. Most classification, even in science, is implicit: it would be ponderous and even unworkable were all classifications to be explicit and insisted upon. Nevertheless, there are problems in science and management much better approached by means of explicated systems of classification. When both science and management must deal with the vast natural-cultural systems we are recognizing as watershed systems, a very adequate system of classification would better be developed, validated, and adopted. Classifications order, even form, what we recognize as domains of nature. They are like systems of hypotheses in that they must reflect something of the nature of objects classified. Even so, they are not simply true or false, for they are formed much according to human purposes: they are tool-like as well as hypothesis-like. Fundamentally, then, classifications should be formed according to our objectives, the point of view or conceptual framework we adopt, and the nature of the objects or systems being classified. Although it is generally recognized that a function of a classification is to so order a domain that we might better understand and deal with it, whatever else a classification may be is not so clear. Some classifications are recognized to have certain predictive capabilities, the table of atomic numbers being an example. And some classifications provide a sort of explanation in being representations that make familiar what was previously unfamiliar. The form of classification we will suggest for watershed systems may even provide causal-like accounts, as it is intended to order in just this way systems that are intractable for mathematical models and theory.

(4) We want to classify the natural-cultural watershed systems that are the upper surface of the earth and the lower surface of the atmosphere and the life between. And we want to do this in as universal a way--that is, in as general and invariant a way--as possible for purposes



of the science and management of watershed systems. The objects or events of watershed systems, which are themselves objects, are best conceived of as being hierarchically ordered, watersheds being incorporated into biogeoclimatic zones, which are incorporated into biogeoclimatic regions. Consistent with our conceptual framework, we must view each object or system in the hierarchy as extending, as it were, for the "life" of that system, which tends to be short for the smallest objects and long for the largest objects. But, relative to its own time scale, the performances or states of the object are variant--indeed, so variant that, for watersheds and smaller objects, performances or states are quite unreliable as a basis for classification. They ought to be classified according to what underlies, determines, and so could explain these performances, what is more general and more invariant. According to our conceptual framework, this would be the capacity of the system, which together with the environmental system determines all possible performances. Such a system would also have to be classified according to its environment, indeed even the capacity of its environment, say climate instead of weather. Any particular performance or state of a system, even a rather long lasting one in human terms, ought to be noted more as an inventory item than as a basis for classification, else one object would keep changing classes. We would, then, classify a watershed by its capacity and its environment. But the environment of a watershed is the biogeoclimatic zone of which it is a part. Thus, a watershed is classified by its capacity and the class of its biogeoclimatic zone, which is classified by its capacity and its environment, the class of the biogeoclimatic region. At the outset, it must be recognized that capacity is an abstract concept and hence difficult concept to deal with empirically. And yet, only such a universal sort of concept can provide an adequate basis for classification of natural-cultural systems as we study and attempt to manage them. Any state or performance of any system is some indication of capacity. Those having experience with systems of a kind generally know quite a lot about the states these systems can assume and thus they have useful insight into the capacities of these systems. It is this sort of insight that must, through the concept of capacity, be the preliminary basis of any adequate classification of watershed systems. More adequate knowledge of the capacities of watersheds and other systems can be developed as performances of systems, initially judged to have the same or similar capacities, are observed under different environmental conditions, this yielding sets of performances partially defining the capacities of systems of a class.

(5) Stream sedimentation and other sorts of "nonpoint-source" pollution will require changes in resource utilization practices to bring about some control. It is supposed that "best management practices" can be specified that will tend to maintain stream systems in desired or acceptable states. We assume that the most direct impact of land use practices such as forestry and agriculture will be on the dendritic systems of small streams draining watersheds. Moreover, we are assuming that, because of the different capacities of watersheds of different classes, best management practices will need to be specified for each class of watershed. In order to determine what practices are to be judged "best," stream systems



as well as resource yield and other considerations will need to be taken into account. Certain standards or goals will need to be set for stream systems of different kinds, such standards being one basis for determining the efficacy of specified management practices. It is our conviction that streams should be classified by the class of their watershed--which is their environment--by their order on the basis of confluence sequences, and by the capacities of their beds to assume different morphological configuration under different environmental conditions. All else--discharge regimes, chemistry, temperature, and biota--would be left implicit: implicit in the class of the watershed, which is the environment determining these other characteristics, even biota, which colonize from the "pool" of species of the watershed and zone. We are concerned to get as universal--as general and invariant--a classification of stream systems as can be achieved. And to deal with hundreds of thousands of miles of small streams, it must be a very simple classification in terms of kinds and amounts of observational experience required for its use in science and in management. Here again, most fundamentally it is the environment and the capacity of a system that most nearly meet these criteria. That universal classification of stream systems as wholes can be so achieved is premised on the assumption that the biota and other implicit characteristics will conform to watershed class, stream order, and the capacity and states of stream physical morphology.

(6) Although in no ordinary sense can a classification be shown to be true or false, validation of a sort is important. In this we are concerned that the classification developed for watershed science and management be representationally adequate for the goals and objectives of these. Representational adequacy for science comes down to whether or not a classification represents a domain in a way that we could understand it; for management, we must in addition require that it be an adequate social tool. Beyond this we are concerned that the classification entail what is essential about the existence, organization, and relations of the systems of interest, a sort of theoretical adequacy. This may entail aspects of dimensional, relational, and dynamical adequacy of the classification. And it must be empirically adequate: we must know how to apply it. In the development of the form of the classification and throughout its specification, there should be assurance that criteria of these sorts are being met. Some "validation" type studies should in addition probably be conducted. But, in the main, determination of the representational adequacy of a generally adequate classification can only come about through its extended use.

(7) One sort of validation study may, however, be important, especially with present concern for stream systems and communities. Because stream biological communities are left only implicit in the system of watershed and stream classification here proposed, adoption of such a system should be preceded by some demonstration that classes of stream communities are concordant with classes of streams based on watershed class, stream order, and streambed morphological capacity. In this, it should not be expected that, when stream systems are perturbed by watershed activities, their biological communities will always superficially

conform to and reflect physical capacities of the stream systems. Moreover, from an environmental control point of view, we perhaps cannot rationally expect stream systems to constantly be in series of most desired states. Although it is not strictly a scientific matter, we might socially best expect to protect the physical and biological capacities of stream systems to return to and remain in desirable states over relatively long periods of time.

(8) Institution of management practices of any sort is premised on the assumption that the causal core of relations determining events in the system to be managed is known, that the major determinants are susceptible to management, and that the effects of this will not be obscured by contingencies. Perhaps because of man's almost geological impact in forestry and agriculture, these conditions of effective management may be quite generally met. In any event, there is the need to determine management practices that will result in necessary resource yields, acceptable stream conditions, and otherwise suitable environmental circumstances. And this must be done for each of the various classes of watersheds, which are apt to respond differently to management practices. Some large-scale, experimental applications of management practices are likely to be necessary, and these should be so conducted as to establish causal relations between the practice, watershed responses, and changes in stream system capacities and states. But enough such studies can hardly be conducted to evaluate management practices for application in all the classes of watersheds of this country. For this, it will be necessary to take advantage of extant relevant experience, which is quite considerable. To do so, it will be necessary to order this experience by the classes of biogeoclimatic regions, zones, and watersheds to which it pertains. Indeed, for the near future, it is more this experience than any that can be developed on which the evaluation of management practice will need to be based.

(9) Institution of best management plans presumably must be based on knowledge of societal needs, goals, and objectives as well as knowledge of the capacities of the natural-cultural systems of interest. Moreover, these capacities and social objectives are apt to vary markedly among regions of the country and thus among watershed classes. Thus, the management practices that are best will need to be determined for each class of watershed. And, although social needs, goals, and objectives are difficult to ascertain and are themselves not invariant, it would be presumptuous to institute best management plans without fully taking into account what may be primary societal concerns. At most, it is difficult to know what is to be meant by "best" management plans. Certainly we are concerned with maintenance of stream capacities and desirable series of states. But we are also concerned with levels of resource yields, and there is apt to be conflict between such goals. Even more fundamental than this is the need to consider societal goals far beyond the near future, even the next few hundred years. Immediate and permanent needs and goals are not likely to be the same. And, yet, our responsibility is to insure the persistence of natural-cultural systems that are good. There has been little, practically none, of this. It would seem best management plans ought somehow to address this problem.

(10) There is a need for specification of alternative rationales for watershed management from which the best can be selected and instituted. A rationale is an argument for doing something in a specified way: it is an explanation or exposition of controlling principles. From its root meaning, we ought to expect a rationale to be rational, but our definition would not insure this. And even though we should seek universal standards of rationality, there must always persist a certain relativity. Rationality may be that which makes understanding possible, pure logical understanding, phenomenal understanding of natural and cultural systems, or humanistic understanding that leads to improvement in human relations. A rationale for watershed management ought in some sense to unify phenomenal understanding and humanistic understanding, phenomenal understanding alone never leading to improved relations among men and between them and their physical and biological environment. In developing and evaluating overall rationales for watershed management--not simply best management plans, which are only a part--we should be concerned with criteria of completeness, rationality, bestness, and common sense. If a rationale is not complete--is not fully specified from conceptual framework through objectives and approach to how it would be evaluated--its rationality simply cannot be examined, cannot be known. Rationality of a rationale entails much but, minimally stated, it must be internally consistent and externally adequate and provide for phenomenal and humanistic understanding. That a rationale exhibit "bestness," that it be chosen best among alternatives, insures only that there is definite effort to develop and evaluate rationales so that a good one can be known, so that rationales are not merely legislated. Finally, if a rationale is not seen as being essentially common sense by most of the critical and enlightened public, not much in the way of success for it can be expected.

## RECOMMENDATIONS

(1) Whatever other processes may have been initiated and however far these may have progressed, there should immediately be begun the development of a series of alternative rationales for watershed resource and environmental management. From among these, the best could then be selected. For this to be possible, each rationale should be complete in that the conceptual framework upon which it is based is specified, goals and objectives are made clear, an adequate system of classification of the natural-cultural systems of concern is proposed, the forms in which criteria, standards, and practices are to be presented are described as are procedures for their monitoring and evaluation, and administrative institutions, procedures for their monitoring and evaluation, and administrative institutions, procedures, and guidelines as well as means for their correction are stated.

(2) It is difficult if not impossible to conceive of a national program of watershed resource and environmental management that is not based on a very universal and hierarchical system of classification of biogeoclimatic regions, biogeoclimatic zones, watersheds, and stream systems. For such a system to be universal--to be general and invariant--it should be based more on the capacities or potentials and the environments of the systems than on their states, which are usually too variant. The nature of a classification system is determined by objectives for it, by the conceptual framework or point of view taken, and by the nature of the objects or systems being classified. It is important that agreement soon be reached on these and the forms of classification needed. Soon thereafter, extensive effort should be devoted to the development, validation, and application of a classification system adequate for watershed management and science.

(3) Watershed and stream system studies intended to be of much scientific and management value should be conducted only on systems that are adequately classified, so that the generality and domain of application of any results can be known.

(4) Cultural systems will roughly correspond to the biogeoclimatic regions of the country; and such conformity can provide a regional natural-cultural and administrative basis for resource and environmental management. The instituting of best management practices presupposes that social needs, goals, and objectives are known as are the capacities of the natural-cultural systems of concern. All of these will vary according to biogeoclimatic regions and zones, even according to watershed classes. It is thus important that specification of these according to regional, zonal, and watershed classes be begun. In this, insuring the persistence of good natural-cultural systems should be foremost, not simply immediate needs or short-term objectives.



(5) In the evaluation of management practices that will be necessary to determine best management practices for each of the classes of watersheds, there may need to be some large-scale experimental studies. But these alone will not soon suffice. It will be necessary to order the already vast empirical knowledge about watershed systems and their management, only an adequate classification making this possible. Such an ordering of watershed experience should usually make it possible to specify at least tentative best management practices, which must be by watershed class.

(6) Much more thought and discussion need to be given to what it is that most must be protected about watershed and stream systems. Is our objective to constantly maintain all parts of these systems near some most desired state, were this to be possible? Or is our objective to protect the physical and biological capacities of these systems to return to and remain in desirable states over relatively long periods of time? This is a matter of the utmost social concern that is rarely discussed, never made clear, and can lead to confusion and even failure of rationales for watershed resource and environmental management.

PART I INTRODUCTION

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## CHAPTER 1

### SCIENCE AND ENVIRONMENTAL MANAGEMENT

#### THE DOMAINS AND PROBLEMS OF SCIENCE AND ENVIRONMENTAL MANAGEMENT

A domain of environmental management, just as a domain of science, is determined only in part by the form of some natural-cultural system, human intentions and the imposition of point of view further determining the domain. Environmental science and environmental management may be concerned with the same natural-cultural system, but because of differences in their objectives and their imposed views, their domains are not the same. In making clear the domains, problems, and objectives of each, it is important to maintain this distinction, if we are to know what to expect of science and what to expect of management.

The system of interest in watershed management is not simply a natural system of topography, climate, soil, and vegetation but also includes social, economic, and technological factors: it is a natural-cultural system. And environmental science pertaining to watershed management must be concerned with essentially this same system. Even though our immediate concern may be protection of stream systems from the effects of erosion, the system of both management and scientific interest should remain the natural-cultural system broadly defined. This is only to say that environmental management is concerned not simply with the protection of certain aspects of natural-cultural systems but with the persistence of the systems themselves, including satisfaction of resource needs. And environmental science also must address itself to the broader system. A more partial view is likely to lead to inadequate science and failure of management.

In the creation and utilization of human environments intended to satisfy needs and aspirations, social problems are perceived: resource problems, cultural problems, political problems, technological problems. Environmental management problems of these kinds may be resolved through human institutions. Environmental science is intended to provide the explanation and understanding of the natural-cultural system necessary to permit such resolution of social problems. To do so, science redefines social problems in ways making their scientific resolution possible. But such redefinition of problems--a common approach to solution in science--may lead to results of little relevance to the social problems originally motivating the science. Environmental science, of watershed systems or

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whatever, to contribute to management, must deal insofar as possible with the common natural-cultural system and with problems defined so as to remain relevant.

#### THE GOALS, OBJECTIVES, AND METHODS OF SCIENCE AND ENVIRONMENTAL MANAGEMENT

It is commonly recognized that to understand or know the meaning of some observed human activity, one must be informed as to its goal or objective. Given a goal, the rationality of effort directed toward that goal can be seen. In light of a goal as a guiding though perhaps not fully attainable ideal, the rationality of more partial but attainable objectives leading toward that goal should be apparent. And the evaluation of methods is possible only relative to stated objectives. The evaluation of goals and objectives must ultimately be in relation to domains and problems of interest. Unfortunately, in matters of science and environmental management, there persists a certain carelessness of statement of problems, goals, and objectives. And the pursuit and evaluation of these human activities are that much weakened.

The goal of environmental management can, perhaps, be most universally stated as the continuous improvement of man's relations with his physical, biological, and social environment. But, even though this statement might be generally accepted, how continuous improvement of man's relations with his environment is understood is not at all likely to be universal, because this will depend on geographic, cultural, technological, and educational heritages and developments of different societies and groups. Common to all societies and groups, however, are tendencies toward narrowness of conception of improved environmental relations and toward favoring local and short range improvements of relations over global and very long range improvements for societies and man.

Environmental management objectives are much more partial and hence more nearly attainable than are goals and should be so stated. Because of the partiality of environmental management objectives, there is a general tendency for them to be the basis for initiation of counter-productive lines of social action. This is a general consequence of difficulties and failures of conceptualization and statement of the nature of particular problems addressed and relationships among these problems in the global and long-term systems producing them, these systems rarely being adequately defined and specified. It is thus of the greatest importance that environmental problems and the objectives related to them not only be clearly stated but also that the full context within which such problems and objectives occur, are perceived, and are stated, be made clear.

We can take the goal of science to be the continuous advance of understanding of natural and cultural systems. Maxwell (1974) argues that understanding is not to be had in any possible universe but rather only in a universe having certain inherent coherence, simplicity, harmony, unity, order, and lawfulness, indeed, a universe that is "intelligible." To understand something is, then, to see it as being essentially

simple, coherent, ordered, and unified. Thus we are assuming that natural and cultural systems are intelligible in these terms. Maxwell goes on to argue that this assumption and the search for understanding, so defined, are entirely rational, even though we have no reason for supposing the systems, in themselves, to be this way. For only in such terms could man understand the world, and his understanding is essential to his persistence and improved relations.

The objectives of science or a particular scientific endeavor are much more partial and hence more nearly attainable than are goals, and they should be so stated. Perhaps the most general objective of scientific endeavor is explanation of natural or cultural phenomena. We can take explanation to be translation of the unfamiliar to the familiar that satisfies the need for explanation. But familiarity and satisfaction are relative. They are dependent on commonality of language and conceptual framework which are thus prior conditions of successful explanation, to which we will need to return. Whereas it is not clear that we do or can achieve understanding, we can always achieve explanations. But explanations are of various kinds and different degrees of adequacy. We must, then, be concerned with criteria of explanatory adequacy.

If, then, the goals and objectives of science are understanding and explanation of natural and cultural systems, not the solution of social problems engendered in these systems, which is the objective of environmental management, how, on the one hand, is science to be distinct from management and, on the other hand, necessary to management? It is our belief that a vigorous science able to fulfill its social function must maintain its distinctness. Similarly, a vigorous management must be held to its function. But effective management is entirely dependent on explanation and understanding of the natural-cultural systems of concern. And it is just with the natural-cultural system that the domains of science and management overlap. It is indirectly through provision of explanation and understanding of systems of interest that science provides for environmental management.

Knowing what it is we intend for science to provide and what it is we intend for environmental management to accomplish, we are in a much better position to evaluate, to select, and to develop procedures providing reasonable expectation of success.

#### THE RESULTS AND EVALUATION OF SCIENCE AND ENVIRONMENTAL MANAGEMENT

Stephen Toulmin (1972), in his treatise on human understanding, argues that rationality is not simply an attribute of a conceptual or logical system but entails the collective human activity by which currently accepted concepts, judgments, and formal systems are evaluated and changed as experience and need dictate. Toulmin is concerned with the development of a philosophy of science adequate to account for the rationality of growth in knowledge. But his concept of rationality need not be restricted simply to scientific knowledge, for it is pertinent to other human activity. Environmental management, just as science, exists in one form or another

at any time and changes from that base in what we hope is a rational way. This entails clear perception not only of goals and objectives but also of domains and problems, for goals and objectives must be evaluated in light of their relevancy to domains and problems, just as methods and results must be evaluated in light of goals and objectives.

Given rational goals and objectives, criteria for evaluation of the results and thus the methods of science are, perhaps, more easily set forth than will be those for environmental management. Perhaps the most fundamental criteria of the adequacy of scientific explanation are internal consistency and external adequacy. Our accounts of natural-cultural systems must not be self-contradictory and they must correspond to what our total experience tells us the system must be like. But no account of any system can be assumed to be ultimate, and, accordingly, we are concerned that our explanations have heuristic power, or the potential to aid us in the creation of more adequate accounts. Beyond this, we expect explanatory power, entailing the completeness, the generality, and the convincingness of an explanation. Ultimately, it is probably the aesthetic criterion that is most determining, because it entails and yet goes beyond other criteria in bringing a sense of economy, proportion, and unity to our evaluations.

Evaluation of the results and thus of the procedures of environmental management is more difficult than evaluation of science but is nonetheless important for man. This greater difficulty would appear to derive from the problem of holistic and yet specific statement of goals and objectives, the problem of determination of precisely what was really done to achieve these, and the problem of determination of what the results actually were. Given adequate statement of goals and objectives, we should expect management procedures to follow logically: they should be rational in the sense of internally consistent. External adequacy of environmental management raises another aspect of rationality: Charles Sanders Peirce argued that what is rational leads to continuous improvement of man's relations with his world. A rational management plan cannot be concerned simply with one aspect of a natural-cultural system, say some quality society chooses to protect, and ignore the other aspects and needs of the system, to its harm. And, like a scientific theory, no management plan can be assumed to be ultimate. To be rational--along the lines of Toulmin's thinking--it must not be permanently fixed: it must provide for self-improvement through evaluative, corrective, and developmental procedures responsive to needs and accumulative experience. Somehow, that which is rational finally seems to be that which is understandable. Considering the complexity of the matter, environmental management programs that are understandable may not be probable. Certainly they appear to be rare events. Yet such understandability must be a goal, because failing this can only mean confusion and failure in resource and quality aspects of environmental management.



## CHAPTER 2

### TOWARD A RATIONALE FOR WATERSHED MANAGEMENT

#### THE EXPECTATION FOR RATIONALITY IN RESOURCE AND ENVIRONMENTAL MANAGEMENT

It has not been shown that in a pluralistic, representational democracy, or in any other technologically advanced society, large scale problems of resource and environmental management can be solved to the satisfaction of concerned groups. The problems of land resource utilization and stream sedimentation with which we will here be concerned can be taken as an example. With good enough reasons, a federal organization, the Environmental Protection Agency, has as one of its important goals major reduction in nonpoint source pollution, of which stream sedimentation is among the most serious. But reduction in stream sedimentation and its undesired effects can only be accomplished by some change in land use practices. This, or course, involves not only most of the lands of the United States and, in one way and another, perhaps most governmental agencies, but also corporate and private businesses and, at least indirectly, every citizen of this country. Just what should be done, just what can be done, and just how we are to proceed is not at all clear. In view of the complexity of such problems, one may doubt the capacity of modern societies to deal effectively with them in the general interest.

Nevertheless, in full recognition of the intractability of the problems confronted, citizens of modern societies have every right and ought to expect that, at a bare minimum, there be rationality in the resource and environmental management programs of their governments. It is a modern tragedy that such rationality of these governments has become nearly the last thing citizens expect. And yet, we must be thankful that at least some can still feel a sense of outrage on becoming aware of some vast governmental program busily undoing what some equally vast program is doing, neither of which may make any sense. But, make any sense to whom? And on what basis? We must suppose that there are those to whom both programs make some sense. Still, the citizen may respond that his common sense tells him that it is wrong for his government to so proceed. The citizen may be right: too often those supposedly more knowledgeable ignore this. Even if the citizen is wrong, there may be a serious problem of sufficient acceptance of programs for them to be successful.

The common sense of an informed citizenry having diverse interests cannot be ignored in effective governmental programs. First, it in all probability contains a broad pattern of rationality, so much so



that Peirce--America's greatest philosopher--took common experience and sense to be the basis of philosophy. It is true that what we may call common sense is culturally conditioned--based on some conceptual framework--and can be wrong. Still, in important matters, this may be exceptional. And the broad cultural themes underlying what we call common sense may need to be taken into account in any successful government program.

What, then, are at least some of the dimensions of this rationality that a citizen has every right and ought to expect of government in resource and environmental management? Perhaps these can roughly be separated into what we may call "formal" aspects of rationality and "informal" aspects of rationality. The formal aspects we can take as having to do with logical arguments making understanding possible. These certainly include clear statement of all related resource and environmental management goals and objectives. Also included would be the conceptual framework within which problems are perceived, objectives stated, and methods worked out. Otherwise, we could not know about the rationality of anything. The "informal" or perhaps, "normative" aspect of the rationality of a program has to do with whether or not it is a "good" program. First, the program must be consistent with the culture and needs of the society in which it is to be instituted, beginning with the assumption that, in some sense, it is a "good" society in the first place. Then, certainly the program should take into account all that is relevant and known and should make use of effective existing institutions and programs, not needlessly create new ones. It should provide mechanisms for continuous evaluation of objectives, procedures and results and should change as necessary to satisfy the global and long term needs of the society. And it must provide for an informed public. Basically, then, in both its formal and informal aspects, rationality involves human understanding. What is understandable is essentially simple, ordered, unified, and good. Some would see this as being just common sense. Certainly it is the rationality that should be expected of resource and environmental management programs.

#### ON THE NEEDED CONTENT OF RATIONALES FOR RESOURCE AND ENVIRONMENTAL MANAGEMENT

A rationale for resource and environmental management must, in some way, deal with these and other problems of rationality. It is an argument for doing something in a specified way. Above all, it must be internally consistent in its goals, objectives, procedures, and anticipated results. To the extent humanly possible, it must also be externally adequate for the culture, needs, and aspirations of a society and for the problems being confronted. And the rationale ought to be clearly set forth, so that it can be examined for these characteristics--examined for its rationality.

In this section, we intend to articulate in a general way the needed content of rationales for resource and environmental management. Just

how these general needs will be met in the development, validation, and articulation of a rationale for watershed management will be summarized in the concluding chapter of this report, after these problems have received extended even if preliminary treatment. For now, all that is necessary is a set of statements giving some indication of the general form of the rationale toward which we will be working.

(1) A conceptual framework and definitions making clear the general nature of the natural-cultural system assumed in development of the management rationale. Social activities, including science, are based on common beliefs, but these are rarely made explicit, so examination of the rationality of the activities is made more difficult, something we want to avoid doing.

(2) A set of resource and environmental management goals and objectives. All importantly related resource and environmental management goals and objectives ought to be set forth. Resource utilization and environmental quality cannot be separated, and continued failure to clearly state and make consistent the objectives of both will lead to counter-productive programs and worse.

(3) A system of classification of the natural-cultural systems, objects, and relations of concern, such a classification to be adequate for and employed in both scientific and management activities.

(4) A set of scientifically-based resource and environmental management criteria specifying the different levels of resource yield and environmental quality that would be expected to prevail were different means and intensities of resource utilization to prevail. The set of criteria should be accompanied with documentation of its theoretical and empirical basis and the logic of its derivation.

(5) A set of resource and environmental management standards and associated practices selected from among the scientifically-based resource and environmental management criteria so as to achieve stated goals and objectives. Social, technological, and economic knowledge and considerations must be involved in the selection standards to be instituted in order to achieve social goals and objectives. Just what this knowledge and these considerations are and how they are to be introduced must be made clear in the rationale.

(6) A set of administrative institutions, procedures, and guidelines for application and enforcement of resource and environmental management standards and practices. This set of institutions and procedures should include and make the best possible use of existing institutions and procedures and include new ones only as this can be shown clearly to effect very substantial improvements in management.

(7) A set of procedures to monitor and evaluate conformity of resource and environmental management standards, practices, and outcomes with stated goals and objectives. In this, it is important that the entire natural-cultural system, including social considerations, be taken

into account. This will require substantial input from a concerned and informed public. In achieving this, neither the informing of the public nor the obtaining of public input should be done in a way to simply re-enforce inadequate programs.

(8) A set of procedures specifying the ways in which resource and environmental management institutions, standards, and practices are to be corrected as necessary to more nearly achieve stated goals and objectives. Inclusion of provision for the "correction" of institutions may not seem realistic to some. But it is realistic if there is to be necessary fundamental change.

#### THE INTENT, APPROACH, AND SCOPE OF THIS REPORT

This report is intended to provide some basis for the development and application of rational programs for management of watershed resources and stream quality. Such rational programs should take into account and deal effectively with natural-cultural systems as wholes, which probably accounts for their scarcity. Natural-cultural systems are ordinarily perceived as being extremely complex, perhaps incomprehensible, to the extent that they are perceived at all. This clearly will not do. Perhaps it will be found that man cannot rationally manage the resources and quality of his environment. But, until then, he must assume that rational management is a real possibility. And to realize this possibility, man must come to understand the natural-cultural systems of which he is a part, for that which he cannot understand he cannot manage. He must, then, come to find natural-cultural systems not as incomprehensible but rather as intelligible, which is to say that these systems are (or are understood as being) essentially simple, ordered, and unified. This is as common sense would have them. And it is our belief that much of what this report entails about natural-cultural systems and all that it entails about their management is little more than common sense.

Even though there may be considerable agreement that much of this report is common sense, we have still to advance compelling reasons for accepting and acting according to common sense. Modern sophistication in science and management may make this more difficult than might be supposed. But we will find that an essentially simple view of natural-cultural systems accords very well with what many scientists and resource managers believe and with sound tendencies in many management programs. We not only have to understand natural-cultural systems as being essentially simple but we also need essentially simple resource and environmental management programs, other ways of understanding and managing showing little promise.

The basis of understanding and management of watershed systems we intend to develop in this report will be a hierarchical classification of biogeoclimatic regions, biogeoclimatic zones, watersheds, and streams according to their environments and their capacities as well

as their performances or present states. To serve its functions in understanding and management, a classification must articulate much theoretical and empirical knowledge. Not all classifications can do this. To insure that this one does, we will need to pay careful attention to its objectives, to the conceptual framework or viewpoint from which it is developed, and to the nature of the systems being classified, because these are the three primary determinants of the form a classification system comes to have. The chapters in Part II, On the Nature of Watershed Systems, are devoted to conceptual framework and definitional interpretation of the fundamental nature of watershed systems. Part III deals with the development of a classification system. Part IV deals with its theoretical, empirical, and practical validation. And Part V is concerned with application of this classification system to resource and environmental management through a rationale, and with sociological, technological, and other considerations that must be taken into account.

Finally, we should reemphasize that this report is not intended to provide a definitive watershed classification system together with a definitive rationale for its application to resource and environmental management. For now, this would be too much to expect. Rather it is the intent of this report to clarify the nature of the problems yet to be faced, to suggest the general forms of a hierarchical classification of watershed systems and a rationale for its application, and to consider procedures and criteria for the development, validation, and application of classifications and rationales. Beyond this, there remains much work to do, it being our hope that the intent and nature of this work will be somewhat clarified by what follows.

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## CHAPTER 3

### CONCEPTUAL FRAMEWORK CONSIDERATION OF WATERSHED SYSTEMS

#### THE FUNCTION AND NATURE OF CONCEPTUAL FRAMEWORKS

We noted, in the previous section, that the nature of a classification system is determined jointly by the objectives for which it was developed, by the point of view, perspective, or conceptual framework adopted in its development, and by the nature of the objects or systems being classified. It was also pointed out that classification of watershed systems will be the basis of the sort of management rationale here to be developed, classification being essential to any rational program of management. But not just any classification system will do. In developing an adequate classification system, careful attention will need to be paid to objectives and, of course, to the empirical nature of the natural systems. But without a sound conceptual foundation or framework, no amount of attention to objectives and the empirical nature of the natural system can lead to a classification system adequate to deal with difficult problems. This is because the conceptual framework articulates the most fundamental understanding that determines how the natural system is to be viewed and what aspects of it must be employed if its classification is to make realizable the objectives. This is one of the reasons that we must first devote attention to conceptual framework consideration of watershed systems.

But explanation and, ultimately, understanding are also essential to resource and environmental management, and conceptual frameworks are deeply involved in explanation and understanding. In Chapter 1, we took an explanation to be a translation from the unfamiliar to the familiar that satisfies the need for explanation. And there it was noted that because familiarity and satisfaction are relative to language and conceptual framework, successful explanation cannot occur without some commonality of these. Much is generally assumed or supposed, consciously or unconsciously, when explanations are proffered. And some failure to communicate, explain, and understand fully can be attributed to this. In matters so important as resource and environmental management, such failure should be avoided to the extent that specification of the assumed conceptual framework can be of value.

It may be that understanding of the physical world is, for the physicist, more or less fully articulated in the brilliant theoretical achievements of physics, as these are formally expressed. It is not,

however, at all clear that present biological understanding--not explanation, but understanding--is articulated by formal theory, which, it is our belief, has so far failed to capture the nature of biological systems. For biology and also the social sciences, it may be that understanding more nearly resides at the informal level of conceptual frameworks than at the level of deductively articulated theory. This may be the most important reason for making conceptual frameworks explicit, as we will here do for one.

Implicit in the foregoing are the ideas that the adequacy of classification is ultimately dependent on the conceptual framework adopted, that explanation and understanding are relative to conceptual frameworks, and that understanding of some domains may indeed mainly reside in conceptual frameworks. That perception, explanation, and understanding depend on prior categories or frameworks underlay the philosophies of Kant and Peirce. Contributing to the demise of logical positivism, which dominated the philosophy of science in the first half of this century, the work of Hanson (1958), Toulmin (1972), Kuhn (1962), and others on difficulties in the theoretical-observational distinction, on social determinants of what we take to be knowledge, and on the growth of knowledge again placed emphasis on the importance of prior conceptual structures. That there may be weaknesses in some of this work and that analytic philosophers of science like Suppe (1977) abhor the relativism it suggests ought not distract our attention from the existence of this categorical relativism and our need to make use of this in classification, explanation, understanding, and their application to resource and environmental management.

Gutting (1973) defined the already prevalent notion of conceptual framework as a set of descriptive generalizations defining a natural domain and a set of procedural rules orienting the activity of a community of scientists toward commonly adopted goals. Rarely are the rules and the supratheoretical generalizations that might define a domain made explicit. Rather, clusters of theories and models, presumably deriving from and thus representing only aspects of some supratheoretical construct, are taken to define the domain. Although this may have a certain advantage of concreteness, it does not provide the overall heuristic guidance ("logic of discovery") or more general--even deeper--understanding a well articulated conceptual framework might provide.

#### A SET OF SYSTEM GENERALIZATIONS

Warren, Allen, and Haefner (MS) tentatively proposed a conceptual framework for biology. This must necessarily have been a personal rather than a communal framework, because no one or few individuals can both present and legislate what may be or are to be the most basic beliefs of a community of scientists. Still, individuals of that community may be able to abstract much of what is fundamental to that community--indeed, their own beliefs no doubt entail much of this. In any event, the biological conceptual framework developed by Warren, Allen, and Haefner consisted of a set of four organismic and environmental system generalizations and

some procedural rules inferred from these. Something like the understanding articulated by the generalizations and the procedures set forth by the rules has been helpful in seeing what the most fundamental biological problems may be, in suggesting possible approaches to these problems, and in determining the adequacy of proposed solutions. It is hoped that making such frameworks available for public scrutiny will improve communication and result in constructive criticism and further developments perhaps strengthening the foundation of biological thought.

Generally, the four organismic-environmental generalizations that were proposed define biological systems implicitly by stating fundamental relationships between organismic systems and their coextensive environmental systems, especially in terms of capacities and performances. The statements are in a natural language and are essentially theoretical in that notions such as organismic system, environmental system, and capacity are not simply observational and are left undefined, except as their meaning emerges from their uses and relationships in the set of generalizations. This was intended to permit interpretation and thus application of the generalizations at any level of biological organization and to increase their heuristic power.

In biological research and teaching over a number of years, we have found these generalizations to be extremely helpful in their intended functions of aiding in problem perception, finding approaches, and evaluating solutions. During that time we have added one simple definitional generalization--system-environment coextension--and one generalization setting forth what we take to be an extremely important principle--system-environment concordance. When confronted with the problem of determining how we might go about understanding and managing watersheds to better protect stream quality, it seemed natural to us to reflect on the fundamental nature of watershed systems with the aid of the biological conceptual framework we had developed. Important aspects of watershed systems, their plant and animal communities, are organismic, and to us the framework seemed very adequate for these aspects. And, of course, everything else could be taken to be in the environmental systems of the organismic systems. But this was not a very satisfactory treatment of physical systems that would be of special interest. Accordingly, we considered to what extent the generalizations could be interpreted usefully and perhaps correctly for any system whatsoever--that is, physical as well as biological systems. Perhaps only because of our poor knowledge of physical systems, we have concluded that the generalizations, so interpreted, can be very useful in understanding physical systems of some sorts. Thus, it is in this form that the generalizations are here presented, what was termed an "organismic system" now simply appearing as "system" in the generalizations.

(1) System-Environment Co-extension

Systems and their environments are necessarily coextensive in time and space.

(2) System Operation, Performance, and Function:

Any performance of any system is an outcome of its operation, which consists of the interactive performances of its subsystems, and has functions or plays operational roles in maintenance and organization of the system and a more encompassing system.

(3) System Potential Capacity, Realized Capacity, and Performance:

The potential capacity of any system predetermines all possible sequences of realized capacities, which in turn determine all possible performances, any occurring sequence of realized capacities depending on the environment through time and any occurring performance depending on the immediately effective environment.

(4) System-Environment Codetermination

Any performance of an open system requires space, time, energy, and materials provided in particular forms and limited amounts by its coextensive environment; potential and realized capacities determine the forms and amounts that will permit performance and thus determine the possible environments within which the system could persist.

(5) System-Environment Concordance

Systems and environments tend toward concordance of their capacities as well as their performances.

(6) System Incorporation

Any system tends to incorporate in some degree not only its subsystems but also their particular environments.

In the following six sections, we will be interpreting these generalizations for physical and biological systems in general and watershed systems in particular and thus, we hope, be illuminating something of the fundamental nature of the latter. But before doing so, we would like to quote Alfred North Whitehead (1929) from the preface of his "Process and Reality," because he says something of why we have had to verge on philosophy and something of our fundamental intent here: "...the true method of philosophical construction is to frame a scheme of ideas the best we can, and unflinchingly to explore the interpretation of experience in terms of that scheme... all constructive thought, on the various special topics of scientific interest, is dominated by some such scheme, unacknowledged, but no less influential in guiding the imagination. The importance of philosophy lies in its sustained effort to make such schemes explicit, and thereby capable of criticism and improvement."

#### INTERPRETATION OF SYSTEM-ENVIRONMENT COEXTENSION

To Alfred North Whitehead, an event was four-dimensional, three in space and one in time. Systems are enduring events, enduring at least long enough for man to perceive or conceive of their existence. The events with which we will here be concerned may extend in time from the length of a storm system, say some days, through the length of life



of an individual organism, say a year, to the duration of its population, perhaps a hundred or more years, and on out to events--or systems--of a geological sort extending for millions of years. What must be emphasized is that the system of interest extends from some past origin, through the present, to some unknown future end. This is so because we are not interested simply in the present state of a system but, nearly always, in prior states and in possible future states, for reasons of understanding and explanation of the system as well as for prediction and possible management. Thus, henceforth in this treatment, when we speak of an individual organism or a watershed, in a system sense, we will mean the life history of the individual organism or the watershed extending from some geological origin to some future geological end. And we will similarly treat other events, objects, or systems, of both short and long duration.

Now it is impossible to conceive of a natural system having no environment, as though it were to exist in a void, uninfluenced by any thing or force. Neither can we conceive of an environment except in relation to some thing, for environment otherwise has no meaning. It is both logically and naturally necessary that with any natural system there is an environmental system coextending in space and time, from the origin and limits of the system to its end. For an organismic system, this is illustrated in Figure 1, but it is so for any sort of system. The term environmental system is here used intentionally, for although an environment can be defined only relative to some system, we will find it useful to be able to think of the environment itself as being an object or system having its own capacities and performances: it is simply that an environment is a relative object.

#### INTERPRETATION OF SYSTEM OPERATION, PERFORMANCE, AND FUNCTION

We become aware of a system because it is or does something. For a natural system to (physically) be something or for it to do something is a performance of that system. The structure of an organism or of a biological community is a performance of that organism or that community: structure was brought into being through development--another sort of performance--and it is maintained by the performances of subsystems. Just as surely, the structure of a rock is a performance of the system "rock." Much more dynamic but no less structure would be that of a storm system. Storms, organisms, communities, and watersheds have structure and do things: these are performances.

Two ways in which we can account for or explain and possibly understand performances of systems are in terms of their operation and in terms of their functions. Operational explanation of the performance of a system is through relating the interactive performances of subsystems on successively lower levels of organization to the performance of interest. This performance can be explained functionally in terms of the role that it plays in the operation of some more incorporating system.



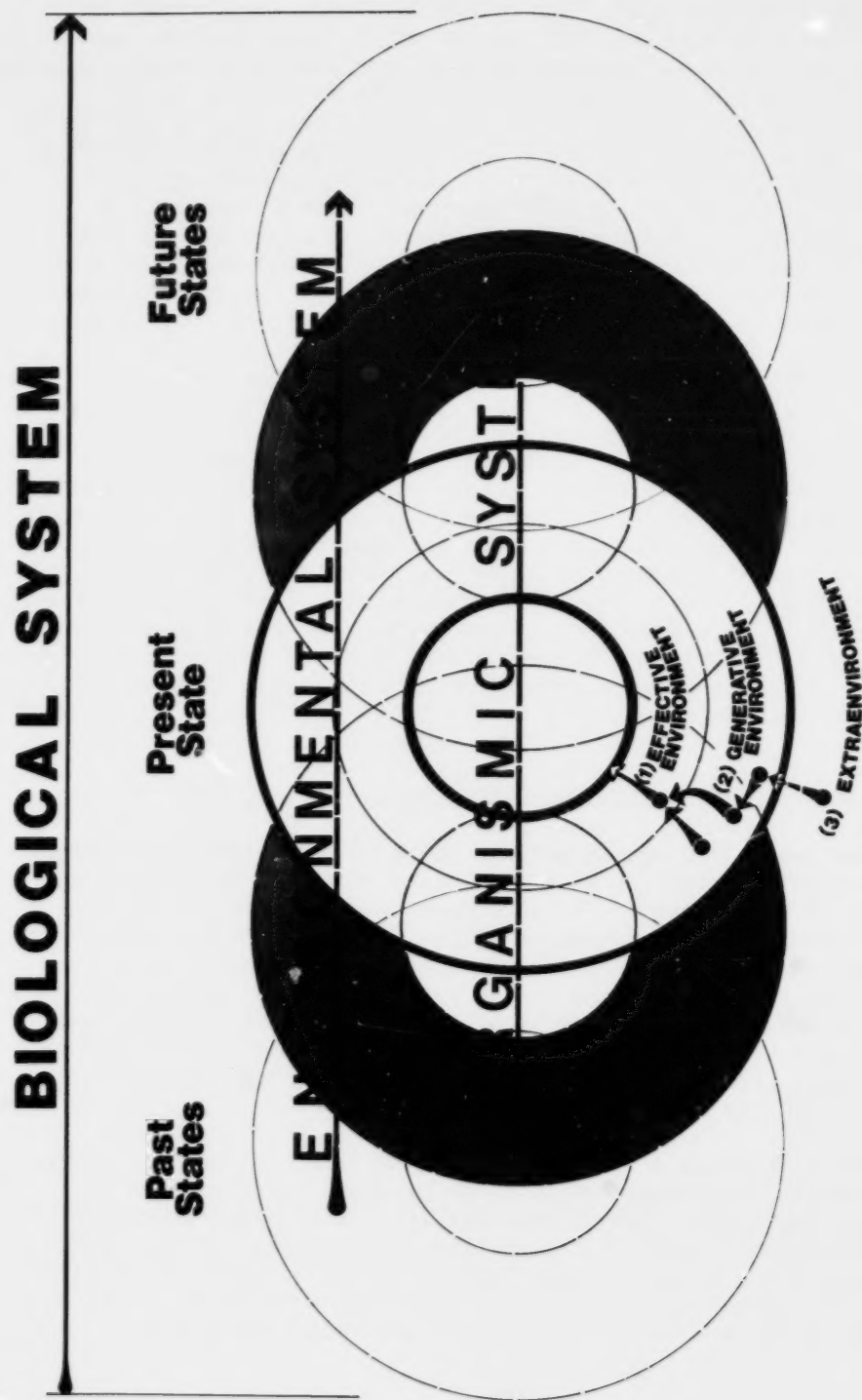


Figure 1. A biological system viewed throughout its existence as being composed of an organismic system together with its spatially and temporally co-extensive environmental system. After Warren, Allen, and Haefner (MS).

## INTERPRETATION OF SYSTEM POTENTIAL CAPACITY AND REALIZED CAPACITY

For a system to exhibit a performance of any kind, it must have the capacity for that performance: again, we are dealing with logical and natural necessity. Now this, in itself, would not be important but that, in a very important sense, it is capacity of a system, not any particular performance, that most interests us. This is so even though capacity is a very abstract theoretical concept amenable only to very indirect and partial evaluation. It is so because performances, such as structure, of systems are in continuous flux, and we want to know what we can expect of a system. What we can expect of a system is entailed in its capacity, which, for each possible set of environmental conditions, will yield a different level of performance of a kind. What a system does at any time is determined by its capacity and its environment at that time.

But, we all know, capacities of natural systems also change, perhaps continuously. Most fundamentally, this is what happens in the development and evolution of systems, both biological and physical. Thus, we must clearly distinguish between the capacity that a system has at any given time and place and what it may have been or may come to be at some other time, in some other place, and under some other environmental conditions. It is useful, then, to distinguish between the (original) potential capacity of a system and the different realized capacities it could come to have under different developmental environments and at different stages in its development in a given environmental system through time. Figure 2 is an attempt to illustrate this for an organismic system, but geological and other physical systems, indeed any natural system, must entail some such capacities. Even when a system has developed to have a particular realized capacity, it still entails some potential capacity for the development of further realized capacities. Realized capacity can be thought of as all possible performances of a system in all possible environments at any time. Potential capacity can be interpreted as all possible realized capacities, and hence all possible performances, in all possible developmental environments. We will find capacity to be an extremely important theoretical concept for classification of watershed systems.

## INTERPRETATION OF SYSTEM-ENVIRONMENT CODETERMINATION

The nature of any natural system is determined by its potential capacity and its environmental system through time and space. This is because natural systems are open: they require from their environments energy and materials in particular forms and amounts. But what forms and amounts of environmental requisites are suitable are determined by the potential and realized capacities of a system. Thus, in a very important sense, the capacities of a system predetermine what environments the system could persist in, or what could be environments of the system. Most fundamentally, the potential capacity of a system determines all possible environments in which the system could possibly persist, whether or not the system could be in them.

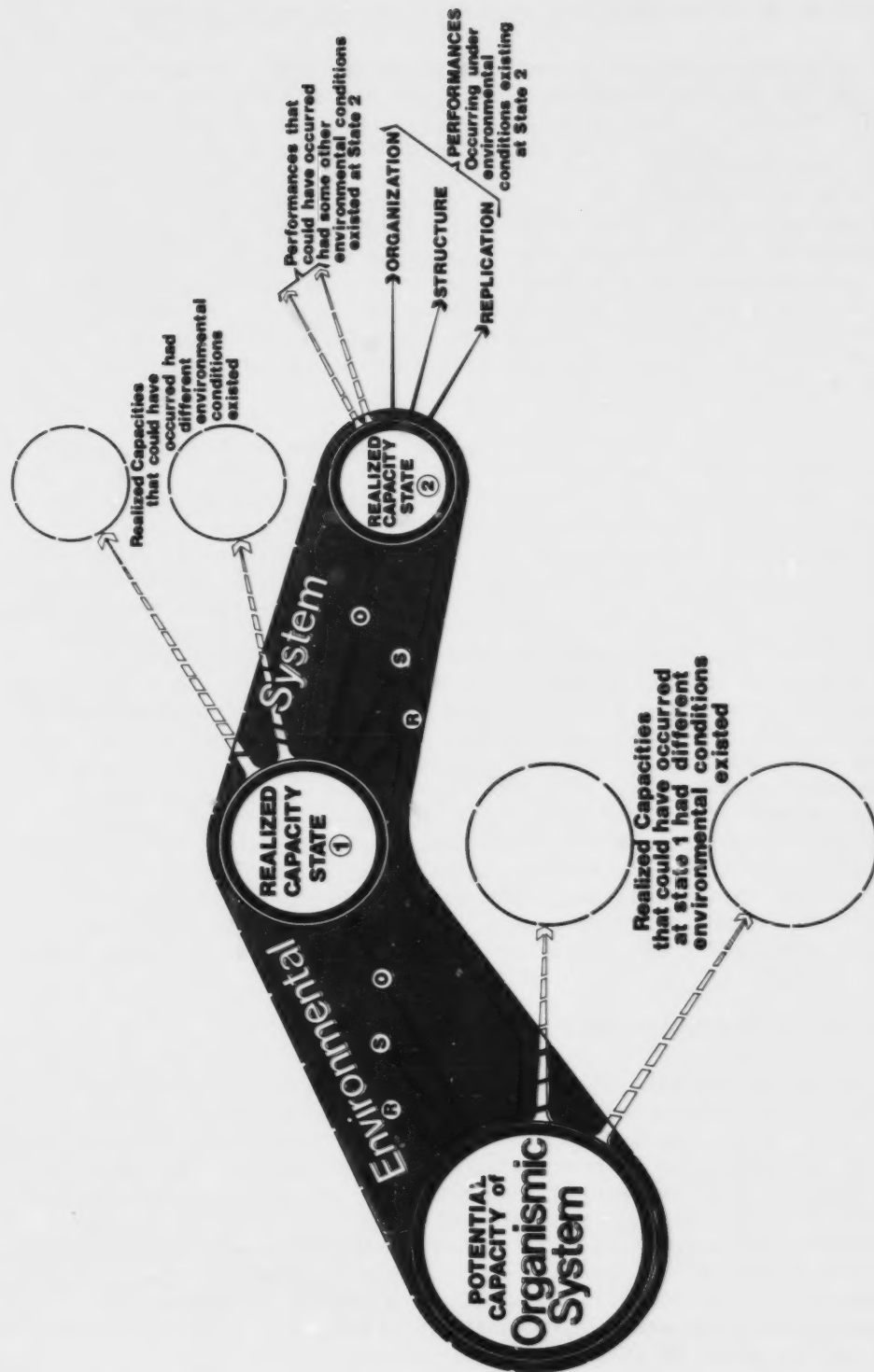


Figure 2. A diagrammatic view of an organismic system showing that from some potential capacity the organismic system passes through a particular sequence of realized capacities jointly determined by its potential capacity and the actually prevailing environmental system. After Warren, Allen, and Haefner (MS).

## INTERPRETATION OF SYSTEM-ENVIRONMENT CONCORDANCE

What it is for a system to be adapted to its environment has not been made at all clear, even in biology, where it is the major theme. To aid in this and some other problems of clarifying the nature of systems, let us introduce the concept of concordance. Dictionary meanings of concordance approximate harmonious relations between two or more entities and rules promulgated to maintain such relations. Use of musical and political metaphors may aid in clarifying the nature of systems and their adaptation. But, first, we must be willing to conceive of the environment of a system as itself being a system. This is to say that the environment of a system is an object or system having its own performances, capacities, and even environment. This too will become important in developing a classification system adequate for watershed science and management. There would be in an adapted system not only present but probable future concordance of its capacities as well as its performances with the capacities and performances of its environmental system.

## INTERPRETATION OF SYSTEM INCORPORATION

It would seem that, by definition, a system incorporates its subsystems or parts. It would also seem, then, that a system must incorporate the environments of its subsystems. But in the interpretation of natural systems, this additional system consequence is not always maintained. And, yet, it has very fundamental implications. The environments of the subsystems of a system are level-specific to those subsystems and are not at all like the environment of the system as a whole. These subsystem environments are determined in large part by other subsystems and, in some sense, by the system as a whole. The degrees of incorporation and concordance of natural systems determine their degrees of organization, integration, and integrity. Each subsystem has its own specific capacity and environment, which lead to its own performances, these interacting with those of other subsystems to lead to the operation of the system as a whole. Diagrammatically, this is represented in Figure 3, which also provides us with another way of conceptualizing capacity that will be of value to us in classification of watershed systems. Because the operation of a system leads to its performances, all possible interactive performances of the subsystems of a system (all possible operational sequences) entail the capacity of that system. This is only to say that we may get some notion of the capacities of natural systems by knowing something about their possible processes.

## SOME POSSIBLE PROCEDURAL RULES.

In an earlier section, we took a conceptual framework to be a set of descriptive generalizations and a set of procedural rules. Even though guidelines like procedural rules no doubt operate in the conduct of a scientific investigation, these are rarely made explicit, except for logical, mathematical, and instrumental manipulation. They would certainly

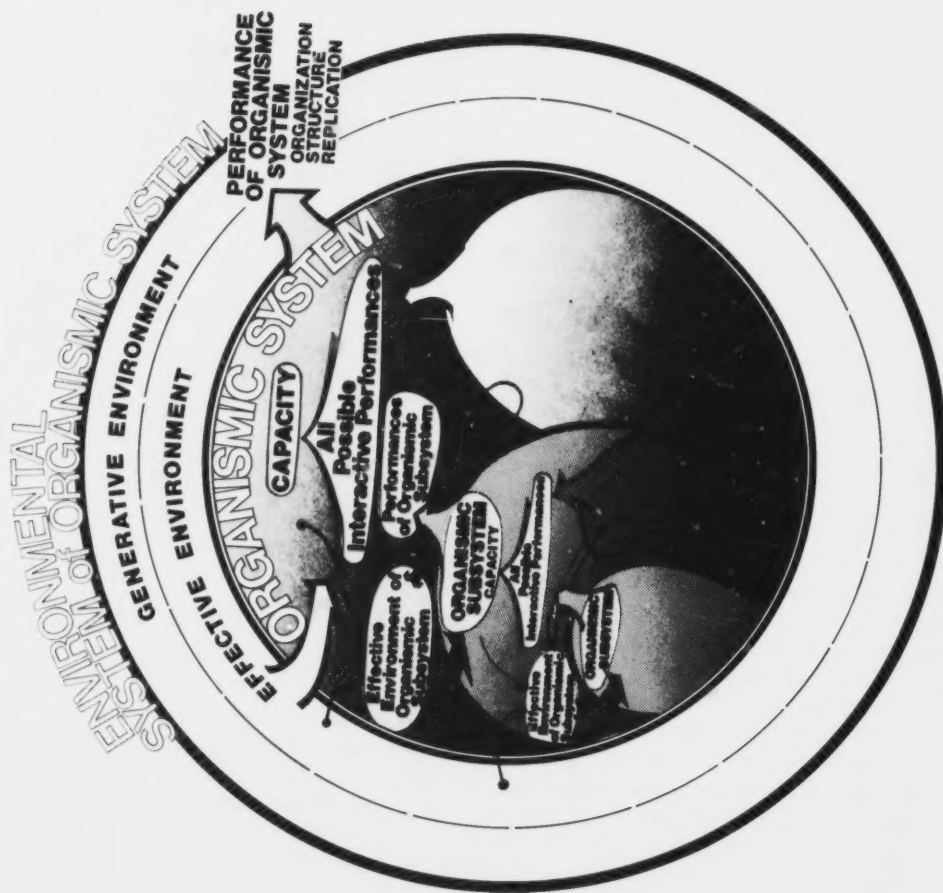


Figure 3. Organismic subsystems and their level-specific environments, all of which are incorporated by an organismic system having its own particular environment. After Warren, Allen, and Haefner (MS).



be different among scientific groups and even among individuals within groups. And it would be neither possible nor interesting to determine what all such rules might be. On the other hand, in the interest of understanding and thus rationality, there may sometimes be value in making clear what may be rules adhered to under particular conceptual frameworks. Defining a domain in a certain way--by the generalizations of a framework--makes possible certain sorts of explanations and approaches and precludes others. Rules say something about this, and they can often be inferred more or less directly from the descriptive generalizations. Because in what follows in this report certain judgments will be made, it is perhaps well to set forth some of the rules as well as the descriptive generalizations underlying these judgments. Thus, even if the judgments are found not to be acceptable, at least their rational basis can be understood. Indeed, procedural rules derived from a set of descriptive generalizations yield another dimension of the meaning of those generalizations: it pertains closely to Peirce's pragmatic meaning. Here we will only present some rules, without further comment or interpretation. Their use, or at least the scientific attitudes they reflect, should be apparent through much of this report.

- (1) Systems and their coextensive, codetermining environments should be defined spacially, temporally, and componentially in ways making possible the forms of explanation being sought.
- (2) Only the performance of a system or subsystem can be measured, its capacity and its operation being representable only indirectly and incompletely.
- (3) Measurements of the performance of a system or subsystem without relevant measurements on its coextensive, level-specific environment are of little explanatory value.
- (4) Sets of performances determined under different sets of environmental conditions are of more explanatory value than particular performances, in that they are more adequate representations of system capacity.
- (5) Operational explanation of a system should take into account the performances and operations of subsystems on successively lower levels of organization and cannot be based only on knowledge of subsystems on the lowest levels of organization.
- (6) Uniformities of simple systems underlie but may be obscured in complex systems.
- (7) Explanatory generalizations pertaining directly to any one level of organization of a system should contain at least one concept specific to that level and subsume conceptual, methodological, or other sorts of indeterminacy that may exist with respect to lower levels of organization.
- (8) Structure and operation differ primarily in spacio-temporal perspective.

(9) Perception and explanation of systems and environments are always partial relative to the space and time dimensions and the components of the systems and environments.

## CHAPTER 4

### DEFINITION OF WATERSHED SYSTEMS

#### THE FUNCTION AND NATURE OF DEFINITION

So long as the generalizations of the conceptual framework were stated as organismic generalizations, we could say that they described, perhaps even defined, a domain--the biological one. But stated simply as systems generalizations, to the extent that they are adequate, their domain becomes much of nature and they hardly define anything, except perhaps one view of any system. We must, then, begin to be more specific with regard to the particular kinds of systems here of interest. We must, with whatever insight we may have gained from the framework, begin to define watershed systems.

Now there has never been much agreement among logicians and philosophers as to just what a definition is, some logicians insisting that only symbols can be defined, that objects of nature can only be described. This position will not do for our needs, and we find in Longergan's (1958) distinction between nominal definition and explanatory definition a position more nearly satisfying our needs. To Longergan, nominal definitions show insight into the use of language whereas explanatory definitions show further insight into the natural objects to which languages may refer. We wish here to emphasize something like this distinction because the term description tends, probably erroneously, to be given the connotation of what can superficially be observed about objects. On the other hand, many will accept that when we define an object, we do something to it as we know it: that is, we do something to our impression and conception of an object by the way we define it. This puts definition and the way we use it at the very core of science. If we are concerned with classification, as we will be here, we must understand what we are doing with definition. Like classification, the way in which we define objects is determined jointly by our objectives, our conceptual framework, and the nature of the object. To achieve our objectives in definition and classification, we impose upon the objects of interest elements of our conceptual framework. We will, for example, be imposing the concept of capacity on watershed systems in order to achieve the classification and understanding we will be needing.

However we accomplish definition in science, its basic function is to render unproblematical that which was problematical, whether it be the meaning of a symbol or the nature of an object. In a very important sense, we define objects in ways making their explanation and, ideally,

understanding possible. Definition must in some degree at least indirectly conform to empirical experience of objects, but explanation and understanding depend on the creative imposition of conceptual framework elements. For the physical world this has been done with very considerable success. But it is not at all clear that this is generally so for the biological world, especially at the organizational level of the biological community, a problem of particular concern in watershed management. We have failed to define communities in ways making their understanding possible. Our approach here will be to define biological communities and other systems of interest in essentially simple, ordered, and unified ways, because of our belief that understanding is ultimately possible only in this way, if it is possible at all.

#### ENVIRONMENTAL SYSTEM, SYSTEM, SYSTEM CAPACITY, AND SYSTEM PERFORMANCE

In working toward universal definition and classification--universal in the sense of general and invariant--we must not ignore but rather account for the flux of perceptual experience by that which is more fundamental. We cannot have a system, whose essential kind has not changed, placed in a different class every time its performance changes, as it will with environmental change. Definition leading to such classification would have failed us: we could not use it to achieve rational objectives of watershed management. Now in the biological world, at least, all is change, but some things change much more slowly than do others. Capacity to perform changes more slowly than does performance, which can change with a momentary change in environment. Capacity changes during development in the same as well as in different environments (Fig. 2). But (original) potential capacity of a particular system does not change and changes only over evolutionary time for a class of systems. Thus it is toward classification by capacity that we must work, if we are to have a usefully universal system.

Now we are concerned with environmental systems, systems, system capacity, and system performance, because it is only performance that happens and will directly affect us, even though it is only capacity that allows us to understand and deal with performance. We will be concerned, then, to define systems according to their capacities as well as their performances. We will also need to define them in terms of their environmental systems, because the performances of a system having a given capacity will be different in different environmental systems. And environmental systems also must be classified by their capacities, such as climate, as well as by their performances, such as weather. We must then, proceed to define or specify, with a bare minimum of formality, the nature of systems.

From Figure 2, we can see that potential capacity is in some sense the integral of all possible realized capacities over all possible developmental environments:

$$\text{Potential Capacity} = \int_{DE_1}^{DE_n} \text{Realized Capacities}$$

And we can further see that a given realized capacity is in some sense the integral of all possible performances over all possible immediately effective environments:

$$\text{Realized Capacity} = \int_{EE_1}^{EE_n} \text{Performances}$$

This latter can perhaps be made more visualizable as in Figure 4. Only two reservations need now be emphasized. Such mathematically and diagrammatic representation erroneously creates the impression of single dimensional rather than n-dimensional environmental and performance space. And it may also create the impression that we have only to measure performances to know capacities, but of course this we cannot do in all possible environments.

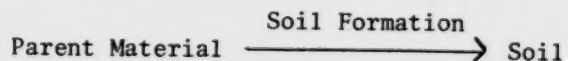
For now we have finally only to note that a particular kind and level of performance (P) at a particular time and place is a function of the realized capacity (C) and the immediately effective environment (E) of the system:

$$P = f(C, E)$$

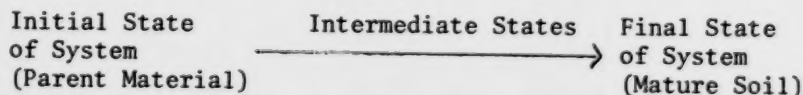
It is in this form that we will proceed to define watershed systems more nearly.

#### FUNCTIONAL-FACTORIAL REPRESENTATION OF WATERSHED SYSTEMS

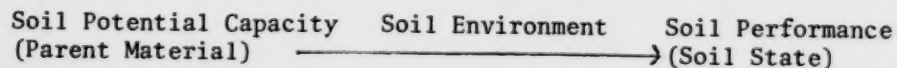
Jenny (1941), in his classic text "Factors of Soil Formation," provides us with an excellent beginning to watershed classification. He saw soils as systems having environments that enter into the processes of soil formation. Soils have their origin in some parent material:



Viewed as a developing system this becomes:



In terms of our conceptual framework, a similar but more general statement would be:





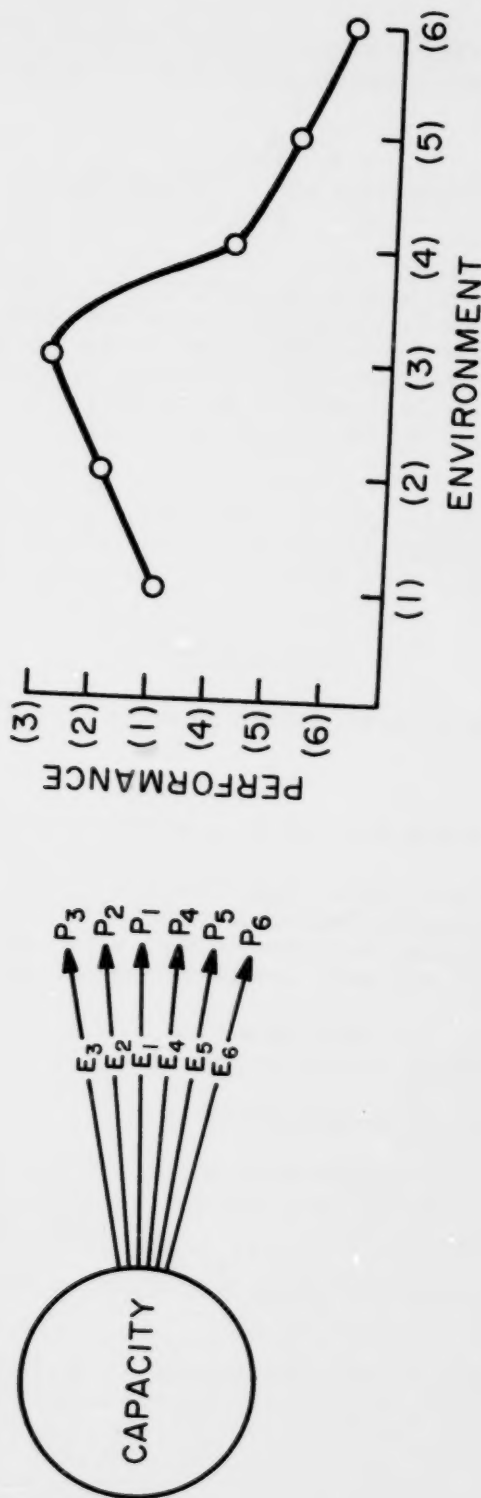


Figure 4. Relationships between capacity, environments, and performances of a system. Any environment leading to any performance is a complex of factors, the entire complex being represented here and being that which leads to a performance. The capacity of a system can be only indirectly and partially evaluated in this way.

Jenny (1941, 1961) has placed great emphasis on soil factor equations in defining, classifying, and explaining soils. Following very similar early views of Dokuchaev and Hilgard, Jenny "defined" any soil property (s) as a function of parent material (p), climate (cl), topography (r), organisms (o), and time (t). We are inclined to interpret his parent material as the (original) potential capacity of material:

$$s_i = f_i(P, cl, r, o, t) \quad (1)$$

Both Jenny (1941) and Major (1951), who applied the same equation to vegetation, emphasize that such functional-factorial representations are more of the nature of definitions than "causal" explanations. In this, they are quite right in emphasizing the logical difficulties of attributing causal relations in complex systems. But, recognizing this, we ought not to lose from our thinking and accounts in classification and explanation the "obvious" causal connections that so greatly increase their power.

Major (1951) interpreted Jenny's equation for vegetation so that any property of vegetation (v) becomes:

$$v_i = f_i(O, p, cl, r, t) \quad (2)$$

where we have capitalized the letter O to distinguish it as a capacity of the vegetation residing in all kinds of plants that can, from surrounding areas, reach the site of the vegetation. We can, for our purposes here, interpret v as any property of a plant and animal community, O then becoming plants and animals able to reach the community site.

We could go on and say that any property (g) of a geological system beginning with some relief (R) and parent material (P)--these being the potential capacity--can be represented as:

$$g_i = f_i(RP, cl, o, t) \quad (3)$$

And Gorham (1961, p. 795) notes that: "Five principal environmental factors--climate, geology, topography, biota, and time--interact to determine ionic concentration and composition of atmospheric precipitation, soil solutions, and lake and river waters...." We could, then, similarly notate the chemical performance of a stream in a watershed. Or its discharge, or its sediment transport, or whatever about a watershed subsystem or system we would choose to so represent. Thus, any performance of a watershed (w), including the state of the system as a whole, can be represented as:

$$w_i = f_i(r, p, cl, o, m, t) \quad (4)$$

Here we have added man (m) as a factor in the environment of the watershed system, as usually will need to be done with the subsystems represented by equations (1), (2), and (3), for obvious reasons.

In the equations we have presented, there remains at least one ambiguity that should be pointed out. A performance (i.e.,  $s_i$ ,  $v_i$ ,  $g_i$ ) of a system is determined by its capacity and a state or performance of its environment. We have noted the capacities of the subsystems of interest clearly enough, say P for parent material in the soil system. But climate (cl) and organisms (o) are, in this context, environmental capacities and not environmental performances. This may be all right and even best, considering the long time period of soil development and the ways in which we would empirically represent these environmental capacities. Still, with this and other equations, interpretation or meaning, which in everything, must be carefully considered.

Finally, Jenny (1941, p. 18) notes that: "Generally speaking, there are two principal methods by which solution of [equations of this sort] may be accomplished: first, in a theoretical manner, by logical deductions from certain premises, and second, empirically by either experimentation or field observation [in which all but one of the factors are nominally kept constant]. At the present youthful stage of soil science, only the observational method--fortified by laboratory analyses of soil samples--can be trusted, and it must be given preference over the theoretical alternative." It is not at all clear that for those sciences upon which watershed management depends this has changed so very much since this was written. However this may be, we will here be relying more on a conceptual framework, definition, classification and extensive empirical work than upon the yet problematical theories and models now available.

#### SYSTEMS OF THE HIERARCHY INCORPORATING WATERSHEDS

We have now to name and define, in a preliminary way, the major systems with which we will be concerned. As will become clearer as we progress through this report, these definitions will be based on our objectives and conceptual framework as well as the nature of the systems. Of particular importance in these definitions are the notions of environmental system, system, incorporation, capacity, and performances, from the conceptual framework outlined in Chapter 3. The functional-factorial representations of watershed system performances, capacities, and environments make more explicit the objects with which we must deal in definition and classification.

The primary objective of this report is to provide a rationale for the science and management of watershed systems that will adequately provide for resource utilization and environmental quality, stream quality in particular. We will be very directly concerned with the protection of stream systems including their biological communities and populations. But, as we will argue, this can be best accomplished through maintenance of the stream physical habitat of the biota. Maintenance of stream habitat systems depends on the capacity of these systems and their environments, the watershed systems within which stream habitats are embedded. And, as we shall see, watersheds are embedded in biogeoclimatic zones and the

zones in biogeoclimatic regions, both logically and, we suppose, naturally. Adequate watershed science and management depend on such a conception of the hierarchy incorporating watersheds. It is this conception we must begin to articulate. In doing so, our definition of these high-level objects will be fundamentally similar but not identical to those of Daubenmire (1968, 1978), Hills (1961), and Krajina (1969).

### Watersheds

We will begin to define this hierarchy with what we are to mean by watershed, which will become the fundamental physical unit of our system of classification and management. It will be easiest if we begin with definition of a biological community. We will take a biological community to be an organismic system composed of interacting systems of species populations at some location. But, according to conceptual framework considerations, we have taken a system to extend through time from some origin to some extinction, as we illustrated in Figure 1. Thus our biological community is not simply what one can observe at a single time and place but is rather the sequence of seral stages extending back into the past to some pioneer stage and into the future to some climax stage, if this has not already been reached. This community can be conceived as having a coextensive environmental system (Fig. 1) including climate, topography, and soil. This four-dimensional community together with its coextensive environmental system we can call an ecosystem. A watershed is composed of parts or all of one or more ecosystems forming a drainage basin. Watersheds of a particular class would have (essentially) the same kinds of communities--necessarily the same stages of communities--the same kind of climate, the same kind of topography, and the same kinds of soil. Moreover, watersheds of the same class would be in the same kind of environment--that is the same class of biogeoclimatic zone. Communities of such watersheds would have the same (organismic) potential capacity, which would be the pool of species present in the zone and able to reach and colonize watersheds of that class.

### Biogeoclimatic Zones

A biogeoclimatic zone is composed of related but different classes of watersheds, or ecosystems that form defined drainage basins. The watersheds of a zone share the same species pool and have many of the same species, but with different dominants and in different proportions. This is because of topographic and edaphic (soil condition) differences as well as local climatic differences among the watershed sites of a biogeoclimatic zone. A biogeoclimatic zone is an area of common macroclimate and, but for local difference owing primarily to relief or topography, would have the same climatic climax community. But, because of these differences, it incorporates watersheds exhibiting topographic and edaphic climaxes as well as climatic climaxes, or stages tending toward these more or less steady state ones.

### Biogeoclimatic Regions

A biogeoclimatic region is composed of related but different classes of biogeoclimatic zones forming a distinctive geographic area, having macroclimates of similar patterns, and having biotas composed of species that historically evolved under similar conditions. These historic geological and biological similarities among different zones can be recognized, such similarities being related to similar patterns of human development and thus forming the most incorporating unit of resource and environmental science and management. Biogeoclimatic regions having similar climates, wherever they occur, tend to develop similar biogeoclimatic formations, which are recognizable, not by species composition, but by similar soils and vegetative structure. This permits some generalization of knowledge over similar regions or formations.

### Watershed Subsystems

We will be concerned with watershed subsystems. But, again, just which of these and how they are to be defined will depend as much on our objectives and conceptual framework as upon the nature of the subsystems. Rather than now attempt in detail to define subsystems of interest, we will only suggest some possible ones. Perhaps it may become useful to define the highest level watershed subsystems as climatic, geological, soil, hydrological, and biological. We may need to separate the biological into tree, shrub, herb, and substrate subcommunities. We will, in this report, be placing particular emphasis on stream systems and their communities, which form very open (and incorporated) ecosystems, or ecosystem subsystems. We will have to direct our attention to what Daubenmire (1968) calls microseres, which are spacio-temporal subcommunities in different stages of succession than is a community as a whole. This concept will be of considerable scientific and management importance, because it can be applied to parts of watersheds experiencing different treatments by man, as generally occurs in forestry and agriculture.

### CONCEPTUAL FRAMEWORK, DEFINITION, CLASSIFICATION, THEORY, AND EMPIRICAL PRACTICE

We have defined only very generally the major systems of the hierarchy incorporating watersheds. Without more explicit statement of objectives, more detailed application of conceptual framework, and more attention to empirical knowledge we could not do otherwise. We will begin to correct this in the next three chapters composing Part III, Development of a Classification of Watershed Systems. What we wish to emphasize before going on is, as we see it, the conceptual continuum of framework, definition, classification, theory, and empirical knowledge, in management as well as in science. That this is a continuum, that the same objects of the framework appear successively more narrowly but explicitly conceived in definition, classification, theory and empirical practice, underlies the thinking and composition of this report. In this way, the various levels of abstraction inform our conceptualization and practice and make them more to the point.



PART III DEVELOPMENT OF A CLASSIFICATION OF WATERSHED SYSTEMS

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## CHAPTER 5

### ON THE NATURE AND USES OF CLASSIFICATION

#### CLASSIFICATION AS TOOL AND AS HYPOTHESIS

In our concern about the development, validation, and application of a classification system adequate for management of watershed resources and protection of stream quality, it is important to begin with some understanding of the nature of classification itself. But, while scientists, often quite effectively, develop and employ classification systems, there is little agreement among philosophers as to the nature of classification, this following quite directly from disagreement over the nature of definition. Philosophers, like the rest of us, would like things to be simpler than they are, this way or that: the problem is that good classifications are of mixed cognitive status. Two important philosophical stances with regard to the cognitive status of classification systems are classifications as "hypotheses" and classifications as "tools." These stances are essentially related to realist views and instrumentalist views of the nature of theories, laws, and other scientific propositions. In the realist view, the theory, the hypothesis, or the classification says something directly about nature that is either true or false. In the instrumentalist view, such conceptual devices are little more than tools for accomplishing particular tasks and therefore are to be judged primarily on the basis of their utility--criteria of truth or falseness not appropriately pertaining. Neither of these extreme views has been successfully defended, the evidence that good classification systems are both "hypothesis-like" and "tool-like" being substantial. In this, they resemble other adequate representations of nature. Good classifications have predictive power and may even resemble explanations, although the latter is not so clear. To this question, we will return in the last section of this chapter, because it can be of considerable importance in watershed science and management.

#### THE DETERMINANTS OF CLASSIFICATION

Certainly in the development and validation but also even in the application of classification systems, we ought to be aware of their determinants, which as noted in earlier chapters we take to be objectives, conceptual framework, and the nature of the objects. It is when we recognize the tool-like aspects and uses of classification systems that we can clearly see the importance of the objectives of classifications in determining how we create them. For it would not be rational to

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design a tool, of any kind, with no objective. And it is when we recognize the hypothesis-like aspects of classification systems that we can clearly see--as Charles Peirce did but William James did not--the importance of the objects of classification and empirical content in determining the form of a classification. We can and must exercise much creative freedom in scientific representation, but ultimately it must pertain to the objects of interest, or the representation itself is of no interest. This pertinence is achieved by abstraction from the objects of interest and may be accomplished in many ways but not in every conceivable way. And criteria of representational adequacy and utility are apt to severely narrow the possibilities. Finally, whatever else they may be, in both their tool-like and hypothesis-like aspects, classifications are conceptual devices. And these must depend, in some way, upon prior views. We do not create tools without blueprints nor hypotheses without some view of nature. The conceptual framework adopted, implicitly or explicitly, is the third important determinant of the nature of a classification system. All these determinants--objectives, conceptual frameworks, and objects--are important not just in the development of a classification system but also in its validation and application.

#### THE OBJECTIVES OF CLASSIFICATION

If the objectives of a classification are to be determinants in its development and validation and to provide guidance in its application, then those objectives ought to be made explicit in a clear and definitive way. This we will begin to do in the next two chapters for biogeoclimatic classification and stream habitat classification. We will need to be concerned with both scientific and management objectives. For now, let us simply reflect on some of the very general objectives, or uses, of classification. Any such effort may indeed be superficial, when we recognize that classification underlies the very possibility of human language, thought, and activity. Let us just say that classifications order domains of human experience. They aid in the identification and characterization of parts and relations and illustrate arrangements such as hierarchical ones. Moreover, they facilitate generalization: science would not, can not, and does not directly deal with all instances of events of any kind. Its generalizations state relationships between theoretical and empirical concepts that are about classes of events and relations, these classes defining the objects of theoretical and empirical investigation. A very good classification becomes a representation of a system and may show relations among its theoretical and empirical objects. This may be so effective as to provide good prediction, as did Mendeleev's periodic classification of elements. Out of systems of classification, generalization, and prediction, there may come effective ordering of human activity toward desired goals, as in resource utilization and environmental management. Criteria and regulations for utilization and management must pertain to classes of natural and cultural systems, because their development and administration for every particular system would probably not be possible and be desirable.

## THE VIEW IMPOSED

There persists in science, and until recently it was prevalent in philosophy, a view--we can call it the "standard empiricist" view--that science makes no (metaphysical) assumptions that cannot in principle be tested, that prior points of view ought not to influence ("bias") interpretation of the data of experience, and that, somehow, scientific propositions are "discovered" in nature, not simply representational creations. It would seem that much of this position ought to be abandoned as an impediment, not just to the understanding of science, but also to scientific advance.

Here we are concerned with views, or conceptual frameworks, "imposed upon" the data of experience, and some justification of this may be helpful to understanding of our position, even for those who find it unacceptable. The imposition of frameworks has been long recognized by philosophers but, until recently, deemphasized. One of Kant's most enduring contributions was his recognition of the role of apriori categories in making possible conceptions, laws, theories, and understanding itself. We need not accept Kant's categories or all of his arguments to appreciate not only that it is impossible to avoid the use of conceptual frameworks in science and other human activities but also that their use is substantially involved in the advance of understanding.

Vague conceptual frameworks are intuitively accepted and used by all of us in all of our rational activities. That conceptual frameworks are rarely made explicit is understandable and may have some advantages. But so also does making conceptual frameworks explicit. For, then, we and others can examine our presuppositions. And these can be kept before us as an aid in problem identification, the finding of useful approaches, and the evaluation of solutions. Conceptual frameworks can provide a high-level ordering of experience and knowledge and thus provide understanding of nature. In a sense, acceptance of a very good conceptual framework should "force" us to see what is most universal about systems of interest and how they are to be best classified, explained, and understood. The conceptual framework that we articulated in Chapter 3 may be inadequate for some needs. But it is intended to fill roles like these, and it will be employed in this way in our treatment of the development, validation, and application of watershed classification systems.

## THE OBJECTS THEMSELVES

Objectives and conceptual framework in large part determine the form of a classification system, but the objects themselves are being classified. It is true that they may be classifiable in an indefinite number of ways--indeed, we need objectives and conceptual framework to choose advantageously among the alternatives. But, finally, were we not to know of objects, we would have no problems of classification, and were the natures of objects not to also in large part determine the form of classification, what the classification pertained to would not be recognizable. Thus, although we may go far in abstraction, and

although there are no definite rules as to what is to be considered similar and how much the differences are to be between classes, it finally comes back to the tool-like nature of classifications: we want to be able to use them. We must, on the basis of some characteristics, recognize sufficient similarities and sufficient differences among objects to allow us to classify them in useful ways.

But of all the kinds of similarities and differences among items in almost any assemblage of objects, which are to be abstracted as dimensions of a classification system? It is precisely here that we need to turn to objectives and conceptual framework for guidance. As an example, let us consider the problem the dynamics of objects presents for classification. Any concrete object or system, on some time scale, is dynamic in its performance, and only performance can we observe. The time-scale of interest in the object may approximate the time scale of substantial changes in the dynamic performance of the object, as it does in watershed systems. Our objective of classifying watershed systems may, say, be to group them for common resource utilization and stream protection practices. But is every watershed system in every different possible (agricultural and forest) vegetative stage--which is an exceedingly dynamic performance--to be placed in a different class? If so, we would have an indefinite number of classes, and no watershed would stay in the same class for very many years: the classification would be worthless in developing resource and environmental management plans. But were some conceptual framework to suggest to us that the capacities and environments of watershed systems are more fundamental and constant than are their performances, and that these can give us a much better indication of possible future performances than does an immediate performance, we would probably choose to base our classification system on capacities and environments and not overemphasize present performances. Then we would not have so many classes with which to deal, watersheds would not change class with a simple change in performance, we could anticipate changes in performance resulting from environmental changes, and we would have the basis for a management plan.

The objects of any classification system must be determinants. But, in general, we want what is most fundamental about the objects to be determining of the form of the classification and their position and behavior in it. They determine the form of the classification in the sense that if objects did not have, say, capacities and environments, then these could not be used to form a classification. But objectives and conceptual framework also determine the classification form, because, without them, we would not know what we wanted and what would be the best way of achieving it. Classifications are intentional abstractions from nature that need (intentional) guidance.

#### THE RESULTANT REPRESENTATIONAL FORM

To fully exploit the possible benefits of classification in watershed science and management, it is important that we understand the full nature of any classification system developed for those purposes. We



have already characterized a classification system as being a "hypothesis" (really a system of hypotheses) about nature. Thus it is, in some sense, a representation of nature--a representational form. We have also said that, from an instrumentalist view of the products of science, it is a "tool." For now, to use a neutral expression, it is a conceptual device, both as a hypothesis and as a tool. But is a classification system anything more than this? This will, of course, depend nearly entirely on the classification system about which this is asked. In what follows, we will have in mind the general form of the classification system we intend here to develop in broad outline.

Clearly, a good classification system is an ordering of a domain of nature. Indeed, Shapere (1977, p. 534) writes of ordered domains as being those "in which types of items are classified, and those classes themselves arranged in some pattern, for example, as a series, according to some rule or principle." In our case, the principles and rules will be those of the previously articulated conceptual framework. Shapere goes on to suggest that orderings of domains are themselves suggestive of fruitful lines of investigation, especially classification--say through refining of distinctions within and extent of domain--and theory elaborating deeper structure of the domain. But can a (very fundamental) classification itself be a theory, or any other kind of explanation? Shapere recognizes the "interactions and interpenetrations" of theory and classification, but he argues that mere predictive power does not make a classification a theory, and that the periodic table of elements is not explanatory. We can certainly agree with the former assertion, but we are uncertain as to precisely what would be expected of a (very good) classification for it to be considered a theory or some other form of explanation. The periodic table is neither the "compositional" form nor "evolutionary" form of theories Shapere appears to be considering: it appears in no way to be a causal account, which, of course, is not always required of explanation. Perhaps, in ordering the domain, it in some sense makes familiar that which was previously unfamiliar and satisfies some need for explanation (Chapter 1 of this report). But our concern here is with another proposed classification system and whether or not it is to be considered as an explanation. It is our belief that, from its roots in the conceptual framework, this classification has not only explanatory properties but causal-explanatory ones, and is the better for it. However this may be--and we will leave as we must the judgment to our reader--there may be benefit in bearing this question in mind as we proceed to develop a classification system.

## CHAPTER 6

### BIOGEOCLIMATIC CLASSIFICATION OF REGIONS, ZONES AND WATERSHEDS

#### THE OBJECTIVES OF BIOGEOCLIMATIC CLASSIFICATION

In proceeding to develop a classification of the regional, zonal, and watershed systems within which are embedded the stream systems we would protect, we have first to consider the objectives of the classification system as these enter into determination of its form (Chapter 5). Then we can impose the conceptual framework to give us the abstract form, and finally we can more fully take into account empirical experience about the objects themselves. Consistent with our argument about the distinctiveness of science and management (Chapter 1), we will present separate sets of objectives of classification for science and for management.

#### Scientific Objectives

- (1) To order the domain of regional and zonal systems of ecosystems including watersheds and streams.
- (2) To provide through the ordering of empirical experience some prediction, explanation, and understanding of the behavior of ecosystems, watershed systems, and subsystems of these.
- (3) To facilitate explanation and understanding of ecosystems, watershed systems, and subsystems of these through making apparent systems, problems, general objects, relations, relative invariances, and possible approaches.
- (4) To provide an ordering of experience about the hierarchical system including watersheds that is dimensionally, dynamically, and empirically adequate for explanation and understanding.

On first reading these scientific objectives of biogeoclimatic classification, one must be struck with their perhaps exceedingly general and ambitious nature. Classification systems are not generally perceived as providing so much, and most of them probably do not. But we are faced with an exceptional problem in watershed science and management, one which we think cannot be adequately handled by direct application of more traditional forms of theory and models. It appears that there is a need for an alternative approach. According to how one interprets the above objectives, perhaps no classification could even nearly achieve them. But the representational form

of the classification system we will consider is intended to make approach to these objectives possible, and we intend a quite literal interpretation of the objectives. Only in this way can they give us much needed guidance.

The ordering of a domain (Objective 1) is or should be the objective of any scientific classification. But prediction, explanation, and understanding achieved through this ordering (Objective 2) would not be so generally possible, recognized, or accepted. We considered this in the last part of Chapter 5 and will return to it again in Chapter 9. For now, we simply believe that this objective forces us to create the best possible classification and that its achievement is possible for the kinds of systems here of interest. Any good classification system should fulfill the heuristic roles demanded in Objective 3. But that a classification be dimensionally, dynamically, and empirically adequate for explanation and understanding (Objective 4) is an expectation going beyond what is apparently expected of much biological theory. Even so, these criteria are so fundamentally important in scientific representation that we have raised them to the status of an objective.

#### Management Objectives

Although scientific objectives need not, and perhaps would better not, be dependent on management objectives, the achievement of management objectives must generally be dependent on explanation and understanding, or scientific objectives. Thus the following management objectives for classification of biogeoclimatic systems presuppose some level of achievement of the previously stated scientific objectives.

- (1) To unify natural and cultural domains involved in watershed resource and environmental management.
- (2) To identify and classify major systems in the hierarchy including ecosystems and watersheds according to common capacities, environments, and responses to environmental conditions including resource utilization and environmental management.
- (3) To provide an adequate basis for integrated watershed resource and environmental management including the maintenance of stream quality.
- (4) To provide an ordering of experience about the hierarchical system including watersheds that is dimensionally, dynamically, and empirically adequate for watershed resource and environmental management.

Here again, now for management, it will be noted that the objectives are very general and ambitious. Yet, if a classification system is indeed to form an adequate basis for watershed resource and environmental management, the demands imposed by these objectives would seem to be minimal. There is no merit in even attempting a classification

the objectives of which are in the first place inadequate to the task ahead. The objectives as generally stated are intended to cover implicitly more particular needs and objectives of particular management efforts, only this being necessary to determine the form of classification needed.

Even with the explanation and understanding projected by the scientific objectives, there remains the need to emphasize the necessary unification of natural and cultural domains (Objective 1), both for understanding and for application of management systems. And if a classification is to adequately serve management purposes, the systems within a class must respond similarly to similar environmental conditions including resource utilization and environmental management (Objective 2). There remains the need to emphasize, whenever we become concerned with particular environmental interests, say stream quality, that management intended to maintain these interests must be integrated so as to maintain other interests, say agricultural or timber production (Objective 3). Finally, dimensional, dynamic, and empirical adequacy of scientific representations (Objective 4) is not simply a scientific need, it is a management need as well.

#### IMPOSITION OF CONCEPTUAL FRAMEWORK AND DEFINITION

With both scientific and management objectives of biogeoclimatic classification of systems including watersheds before us, we have now to impose the articulated conceptual framework onto nature and to refine our definitions of the objects and relations of these systems. This conceptual framework and preliminary definitions were presented in Chapters 3 and 4. We need not now so much review these but rather employ them, with our objectives in mind, to identify what there may be about biogeoclimatic systems that will enable us to so classify them as to achieve our scientific and environmental management objectives. We will begin by such inspection of communities and ecosystems, then move on to biogeoclimatic zones, then watershed systems, and finally biogeoclimatic regions. At each level of organization we will be employing conceptual framework principles of coextension, operation-performance-function, capacity-performance, codetermination, concordance, and incorporation. We will employ these principles as means of abstracting from the natural systems what is most fundamental about their objects and relations, so that what is most fundamental can become the form of the classification, which we will take up in a later section.

#### The Community, its Environment, and the Ecosystem

We will find it easiest to begin with the biological community and its coextensive environment, which together form what is generally referred to as an ecosystem. Consistent with generalization 1 of the conceptual framework, the community of which we here speak is a continuum in time and space: it is the entire sequence of seral or developmental states from the pioneer stage of community origin through intermediate successional stages into some sort of climax stage, as illustrated in Figure 5. It is this four-dimensional object--of very considerable temporal as well as spacial extent--that most interests us for both

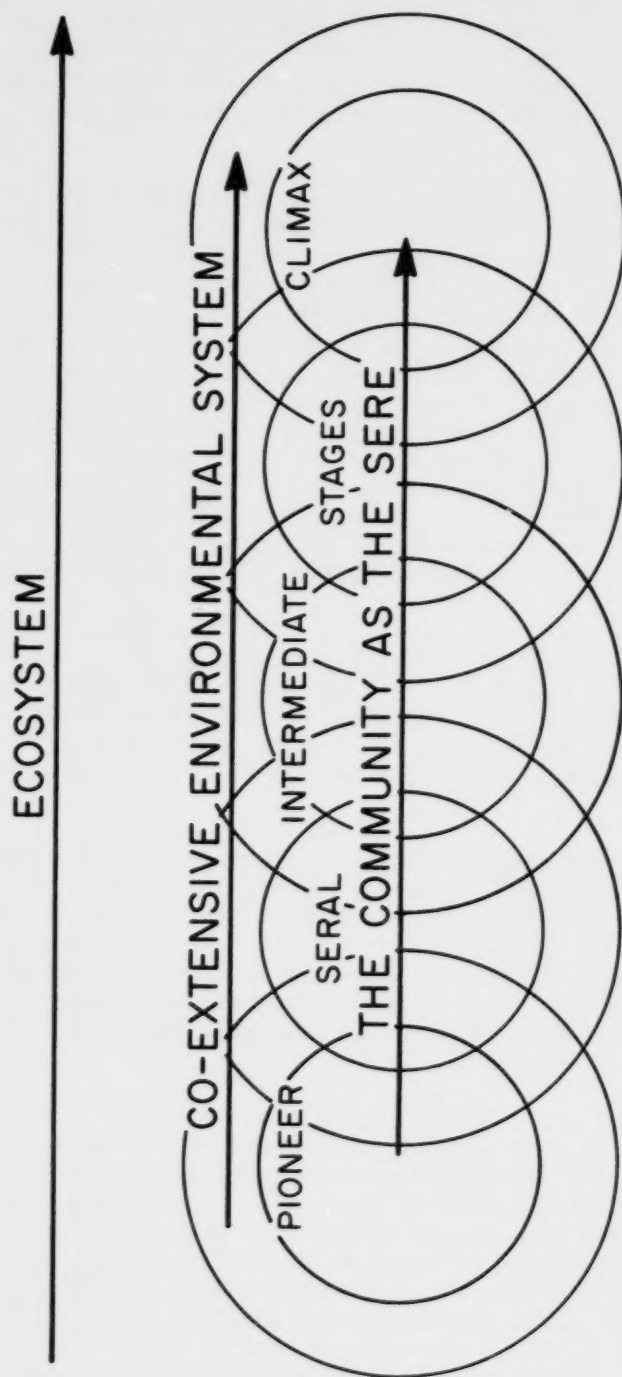


Figure 5. Interpretation of Figure 1 for the biological community, which then becomes the series of states from its origin through its climax. Coextensive with this community as a sere is an environmental system, and together these form an ecosystem extending in time as well as space.



scientific and management purposes, not primarily any particular state of this object or system. And biological communities in this sense are what must be adequately classified. Coextensive in time and space with the community as the sere is its (physical) environmental system, any particular community state having its associated environmental state, such an association forming one state of an ecosystem, the series of associations forming an ecosystem.

According primarily to local climate and organisms able to reach and colonize a location, community succession to some sort of a climax stage will occur. As a system, the community has the capacity to so develop, from some original (organismic) potential capacity through the realized capacities of each of the seral stages (Fig. 2). Black alder forest succession in Northwest Germany is illustrated in Figure 6. What becomes apparent is that, according to environmental conditions and available colonizing species populations, a community passes through a sequence of structures, none of which alone can characterize the community, unless perhaps the final or climax stage can do so. This is to say that to classify a community object adequately, we must do so more on the basis of its capacity and its environment than on the basis of any particular stage. Otherwise our object would be changing its class as it realized its own developmental capacity or responded to some environmental change.

Within the boundaries of what we may take to be a biological community, there may be very local disturbances: a clear cut in a forest; a small burn on a prairie. Secondary succession will generally occur on these areas, but they may be so limited in extent and so otherwise like the surrounding community that we hesitate to treat them as distinct communities, for classification, for explanation, and for management. Such subcommunities we can call microseres.

We will, in the next section, be considering three kinds of community climax: climatic climax, topographic climax, and edaphic climax. But there is one sort of climax we should note in this section. Inspection of Figure 6 shows that, in the black alder forest succession, clearing, mowing, draining, and fertilizing lead to community stages that can be perpetuated through management. Such stages we can call disclimaxes, which are essentially what is maintained in agricultural land use, when man alters the environment of the community.

For those familiar--or who will become familiar--with the history of plant community ecology in this century, a footnote on the controversy about the organismic and individualistic conceptions of the plant community is here needed. This is because imposition of the conceptual framework may to some readers seem not to account for what is useful in the individualistic conception. To those holding this conception, from Gleason (1917) to Whittaker (1962), plant communities were hardly natural entities amenable to field definition and anything but classification of convenience, or so these advocates seemed to argue. It seems to us that what these workers mainly were contributing was some knowledge of the distribution of populations within and between

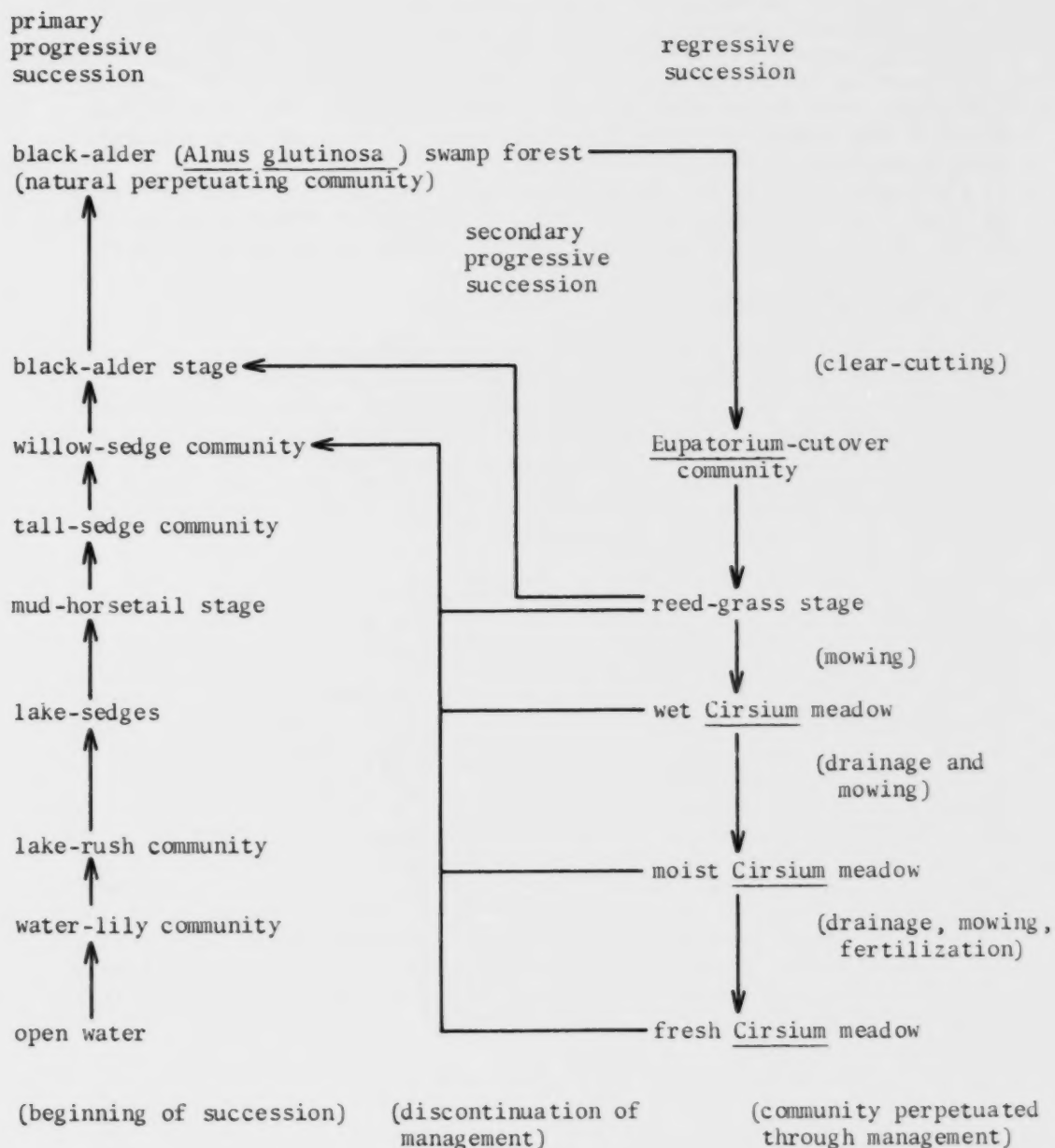


Figure 6. Black-alder forest successions in Northwest Germany. Primary and secondary succession are shown. Of particular interest are the various disclimax stages in which the community can be held by various land management practices. (After Tuxen and Preising, 1942; and Mueller-Dombois and Ellenberg, 1974).

communities, of the origin of communities, and of empirical difficulties in the study of communities. They, just as had Clements (1916) with his excessively metaphorical organismic view, went beyond the empirically and theoretically useful bases of their understanding and adopted untenable positions, from which there is some present retreat. The view of communities and community classification presented here may not rest easily with those holding strong individualistic views, but that which is important in their position can be accommodated, and they have provided no viable alternatives. The empirical problems of delimiting communities in nature, which they so correctly emphasize, we will touch on in later sections.

### The Biogeoclimatic Zone

Were we to look out over some large landscape from some sufficiently high vantage, we would be likely to observe some topographic relief and a mosaic of vegetation. Now were this area to have a common macroclimate, common zonal soils, and a common pool of plant and animal species supported and drawn from by the incorporated biological communities, we could think of it as a biogeoclimatic zone. Such a zone is an exceedingly complex system but is fundamental to our understanding of what it incorporates and what it means to watershed management.

Hills (1952, 1961) adopted essentially a biogeoclimatic view in his studies and classification of lands of Ontario, he too being concerned with establishing a sound basis for land and water resource management. Figure 7, in a very simplified way, illustrates how topography, even in an area of uniform macroclimate, leads to differences in local climates and soil conditions. Within this zone, biological communities will tend toward edaphic, topographic, or climatic climaxes according to local climatic and soil conditions. Were there no physical relief--were the common macroclimate to lead to the same local climates and soil conditions--then the (abstract) climatic climax would (theoretically) come to prevail over the entire area. The area over which, in an indefinite period of time, the climatic climax would come to prevail is another way of defining a biogeoclimatic zone. But in reality, so to speak, differences in local climates and soils lead to differences in the climax communities that can be expected to be reached. Thus, according to soils and topography, we find edaphic and topographic climaxes, as well as the climatic climax on mesic soils, all within the same biogeoclimatic zone.

But, for a given zone, all communities are not likely to be in their climax stages, be they edaphic, topographic, or climax. Rather, because of disturbances, some of them are likely to be in various stages of secondary succession. Thus, over a landscape, we may observe a mosaic of vegetation identifying biological communities, some in edaphic, some in topographic, and some in climatic climaxes, but others in various seral stages leading to these, and still others perhaps in disclimaxes, where man's activities are maintaining them so. Each of these identified communities together with its local climate and soils is an ecosystem in some stage of development. And, all together, these ecosystems form a biogeoclimatic zone. In a very important sense, the zone is the

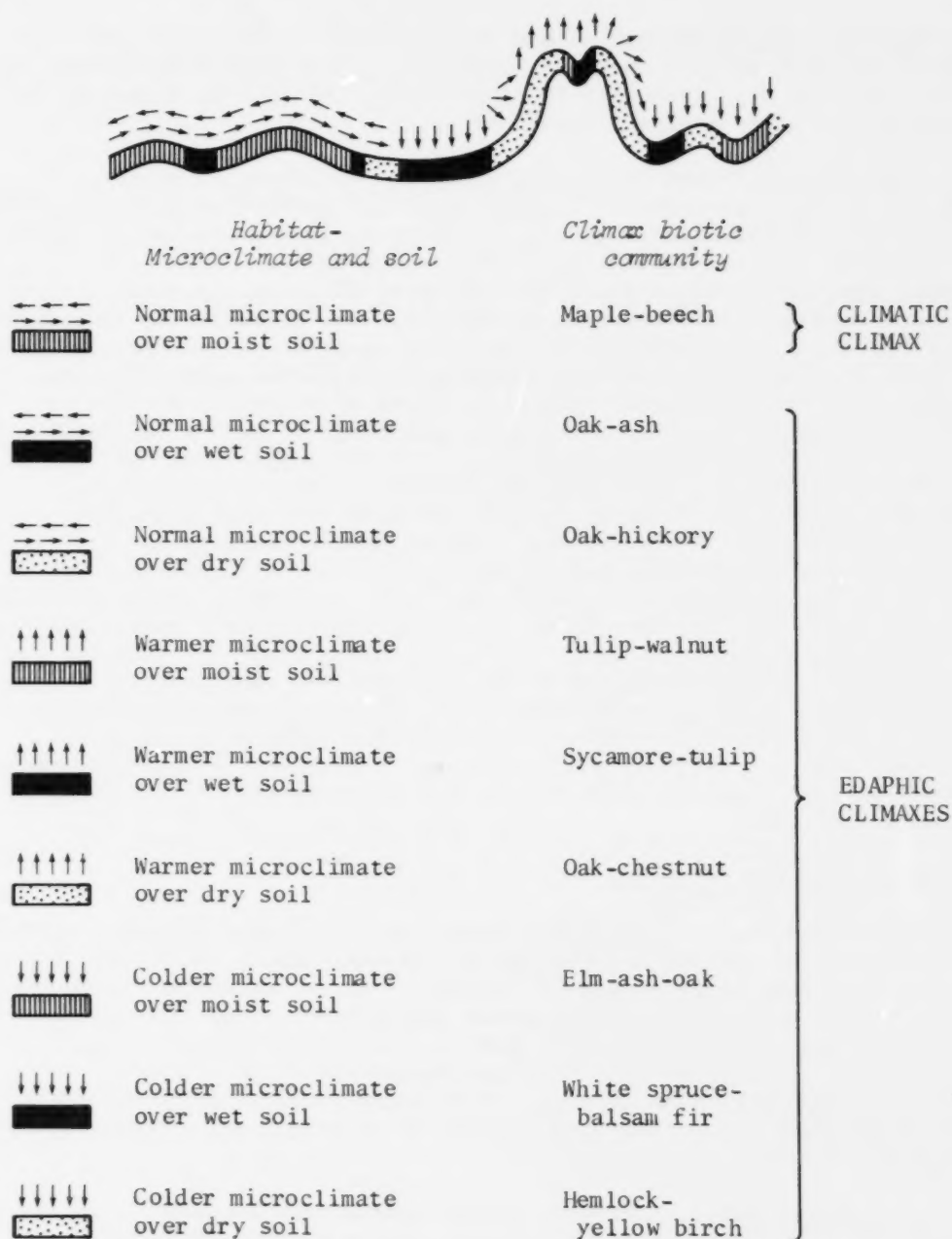


Figure 7. Different forest climaxes occurring in southern Ontario. The climatic climax theoretically would occur over the entire region but for topography leading to different local climates, which partially determine different edaphic or soil conditions. On these areas different edaphic climaxes occur, the climatic climax occurring only on mesic soils. (After Hills, 1942; and Odum, 1971).

environmental system of each of the ecosystems it incorporates, as generalization 6 of the conceptual framework and Figures 3 and 8 suggest. This, it will turn out, is fundamental, and will be a part of the abstract form of ecosystem classification.

We now must return to the matter of the (organismic) potential capacity of the ecosystems of a zone, which can perhaps be best seen with the aid of a diagram like Figure 9, which is an interpretation of Figure 2. Residing in a zone are all the species populations of plants and animals that can colonize the different local habitats, to establish and maintain community and ecosystem succession. But climatically and edaphically different local habitats are amenable to different species combinations, so kinds of different communities develop on different kinds of sites, similar kinds of communities on similar kinds of sites. A particular community, during succession, comes at each stage to have a different realized capacity for performances like structure, timber production, or further development. But all the communities of a biogeoclimatic zone are intimately related in sharing the same potential organismic capacity and macroclimatic system. They will share many of the same species, though there will be distinctive differences in species composition of seres occurring under different local conditions. Yet, the gross appearances of at least the climax stages of the different local communities will be quite similar: prairie, steppe, coniferous forest, or some man-maintained stage of these, as examples. And, over the zone, there will generally occur the same zonal soil, the product of similar climatic and vegetative history (Fig. 10). But differences in parent material and local climatic and topographic conditions can lead to complexes of soil series. Both of these points lead to problems and possibilities of classification.

#### The Biogeoclimatic Watershed

Watersheds have historically been objects of human concern: either as a part of the watershed system or of its environment, human cultural activity has come to be generally involved. It is, of course, also involved in ecosystems and biogeoclimatic zones, but these systems are physically more difficult to define. A watershed is not only an object of human interest, it is an object the physical boundaries of which are generally quite apparent, even obvious. This focus of human interest and this ease of physical definition make watersheds of exceptional scientific and management interest.

A biogeoclimatic watershed, in the view we are imposing, is a system of climate, topography, substrate, water, and organisms extending over geological periods of time, longer, for example, than any particular biological community, which may exist for thousands of years. Not all of our interests in watersheds need be about their entire geological histories, but it is critical that we recognize the watershed object of interest and importance to be not simply what is apparent at any time, not simply a state of the system, but rather a long sequence of states beginning in the past and extending into the future.



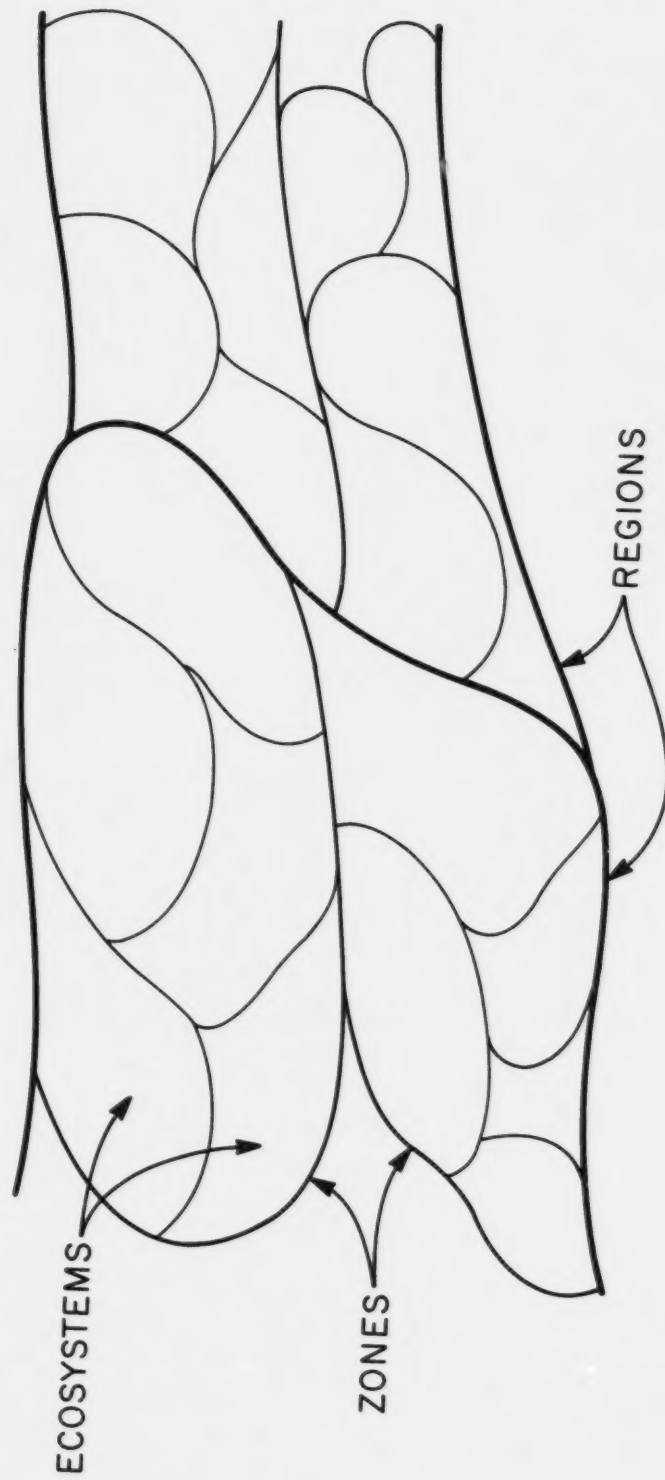


Figure 8. Representation of how ecosystems are incorporated into biogeoclimatic zones, which are incorporated into biogeoclimatic regions. An ecosystem which includes the environment of a community has a biogeographic zone as its environment. The biogeographic region is the environment of a biogeographic zone.

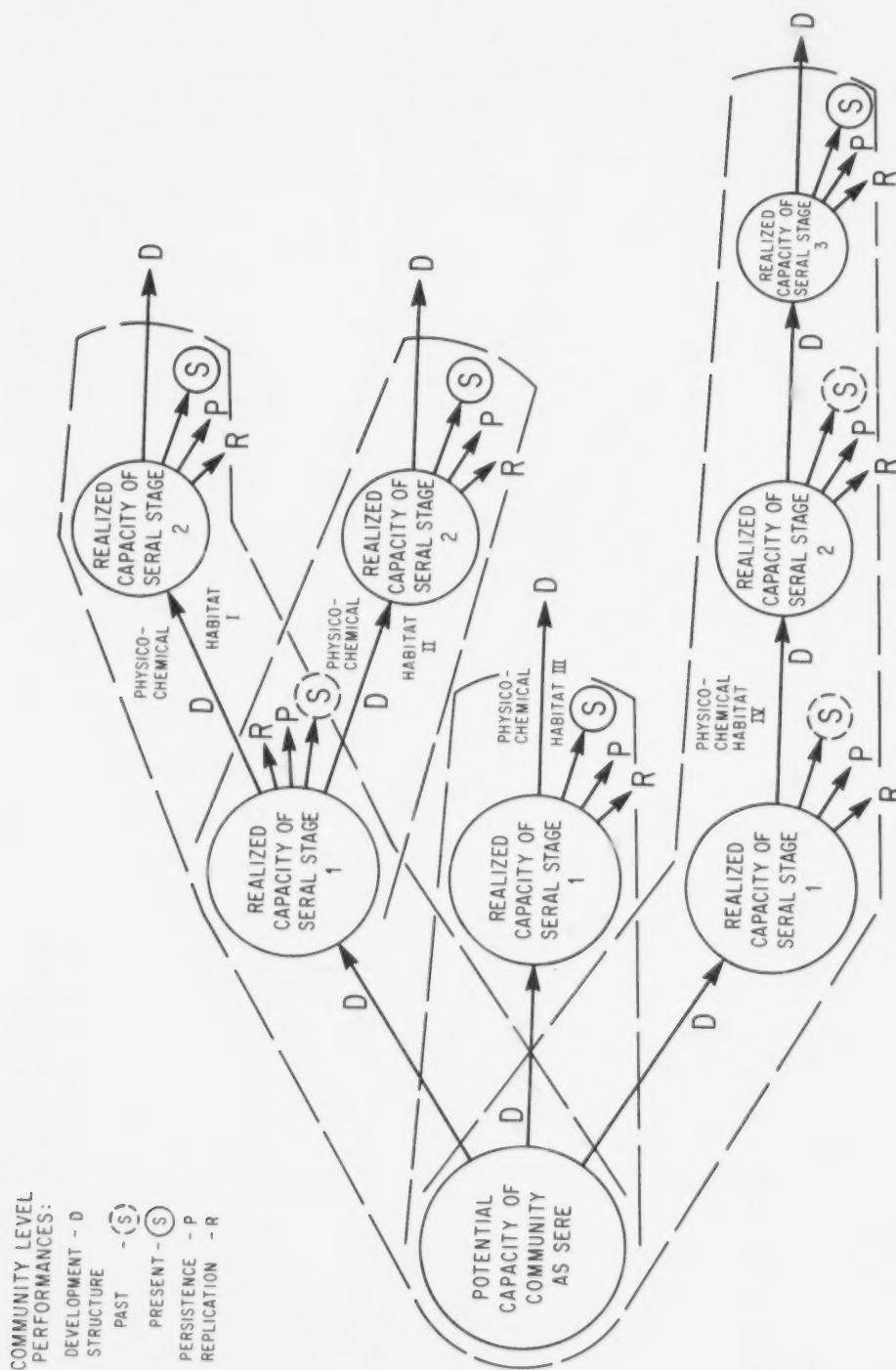


Figure 9. Interpretation of Figure 2 for a landscape over which a climatic climax would theoretically occur but for topographic and edaphic differences which lead to topographic and edaphic climaxes. The system over which the climatic climax would occur is a biogeographic zone, the species of which form a pool (potential capacity) from which all community seres of the zone develop.

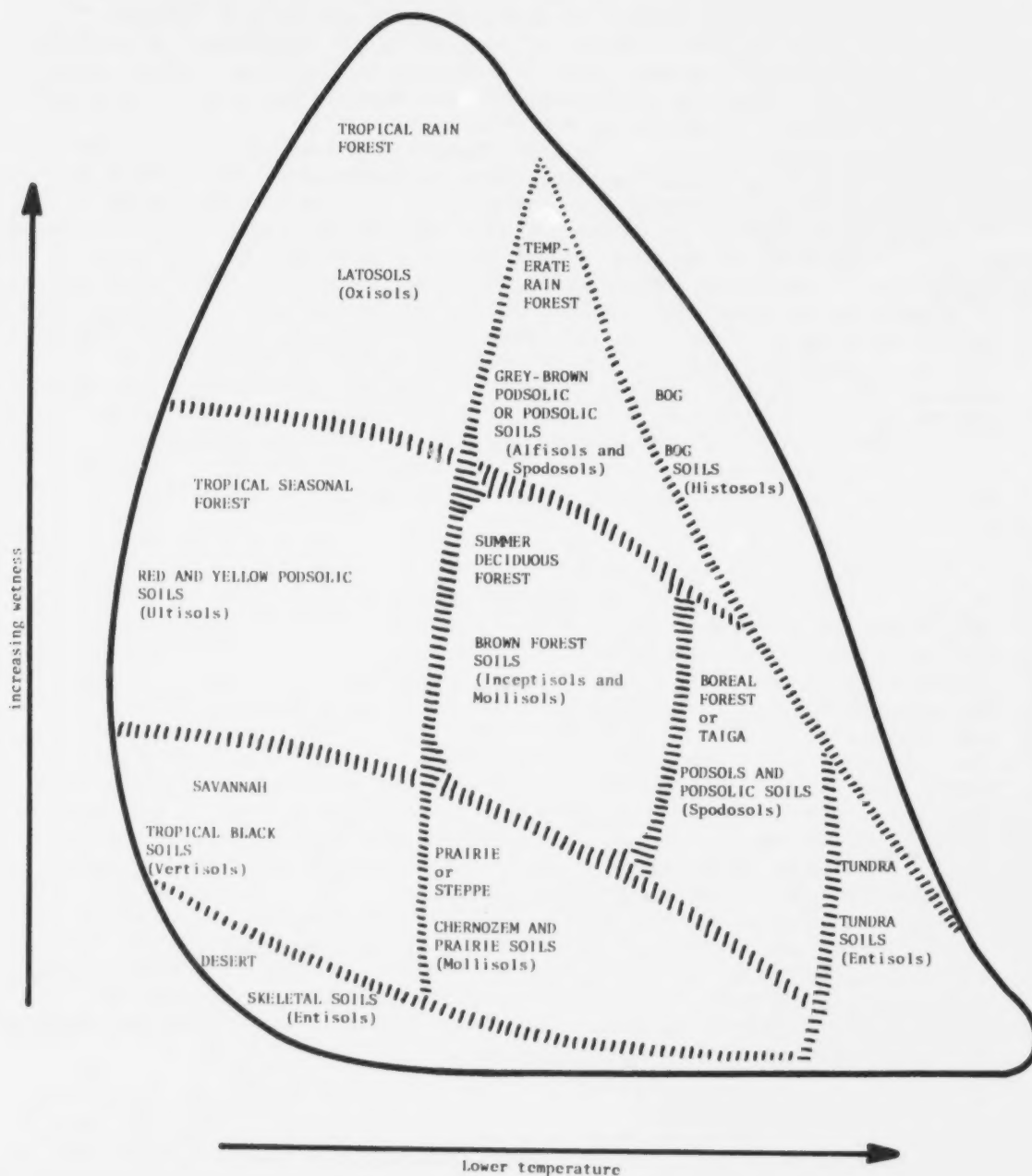


Figure 10. The geographic distribution of soil types in relation to climatic temperature and wetness regions. (After Muckenhirn et al., 1949; and Etherington, 1975.)

Imposed through the conceptual framework is the notion that any state of a watershed system is a performance of that system. So also would be the continuous change of state--such as occurs with forest succession--that we should expect of such systems. Subsystems of a watershed also have performances: soil development and wasting, timber production and yield, streambed configuration, and stream discharge being possible examples. For a biogeoclimatic watershed system or any of its subsystems to have such performances, it is both logically and naturally necessary for them to have the capacities for these performances. And because we are interested in watersheds over rather long periods of time, we are really more interested in such capacities than in any particular performance: we are interested, as it were, in all possible performances, that we might better understand and manage watersheds. Moreover, most watershed performances are relatively rapidly moving objects in phase space. Capacity, on the other hand, is a relatively more slowly moving (theoretical) object. And it is primarily on the basis of such slowly moving objects that systems should be classified. We have, then, a conformity of scientific and management interest in the capacity of watersheds. We must also be interested in their environments and classify them on this basis too, for the performances by which we know and are affected by systems are determined by their capacities and environments together (Fig. 2, 3, 4).

Now watersheds are physically defined (or bounded) as drainage systems. Here, for both scientific and management purposes, we will in general be concerned with no higher than fourth order watersheds. Scientific and management problems and possible solutions become different with higher order and thus more geographically extensive systems. We will, of course, be dealing with such large geographic areas, but our natural units will be relatively small watersheds. But what are the relations of biogeoclimatic watersheds to ecosystems and biogeoclimatic zones? This will be primarily determined by topography, as it will determine, within a given macroclimate, local climates, soils, and vegetation. According to topographic relief, a particular watershed may be only a part of a large ecosystem, may itself form an ecosystem, or may include parts or all of two or more ecosystems. This, of course, has natural, scientific and management implications. But the well-defined boundaries of nearly all drainage basins give watersheds as systems an identifiable physical structure that is a real scientific and management advantage. Ecosystems, as those holding the individualistic view of plant communities have so emphasized, must generally be arbitrarily bounded, the same applying to biogeoclimatic zones.

#### The Biogeoclimatic Region

We have noted that, in some sense, the biogeoclimatic zone is the environment of a particular ecosystem--not of a community, which together with its own coextensive environment forms an ecosystem. But even sometimes so vast a system as a biogeoclimatic zone must not be thought to exist, as it were, suspended in a vacuum. For, were we to so think, not only our science but our management would be the poorer. The environment

of a biogeoclimatic zone becomes, in our imposed view, the biogeoclimatic region within which it is incorporated (Fig. 8).

We will take a biogeoclimatic region to be a system composed of closely related and physically associated biogeoclimatic zones. It is a kind of system generally occupying a large contiguous area of subcontinental scale. The zones of a biogeoclimatic region are subsystems that are related and associated because of rather common geological, climatic, and evolutionary histories. Somewhat similar macroclimate, zonal soils, and vegetative structure prevails over a region, although zonal climates, soils, and biotas, can be distinguished. The vegetative communities of the different zones of a region are, generally, composed of different species. But the growth forms or structures of the dominant species throughout the region are sufficiently similar that the communities of a region have a superficial physical similarity in appearance: it is all prairie grass, or chaparral, or coniferous forest, as examples. Such a system, defined on the basis of physical appearance, not species composition, is known as a plant formation or a (plant and animal) biome. Over the world, there are formation or biome classes defined by such appearances, examples of the same classes appearing where climates are similar, regardless of species: thus there is the chaparral formation, which occurs along the Mediterranean as well as along the California coast.

Biogeoclimatic regions also (broadly) define human cultural systems, which can be thought to be incorporated into the regions as systems. For the biogeoclimatic capacity of a region and the capacity of its cultural subsystem largely determine the broad form of the cultural system that develops. And the roots of such cultural systems extend down through the zones of a region and into its local ecosystems. We have, then, another important reason for extending our view to encompass at least regions. Of course, culturally, economically, and politically, even this is not enough: we can define all else, for our purposes, as being in the environment of the biogeoclimatic region of interest.

#### THE FORM OF BIOGEOCLIMATIC CLASSIFICATION

With our objectives and the results of imposition of conceptual framework and definitions of biogeoclimatic systems before us, we have now to abduce a form for biogeoclimatic classification that is adequate. It is this form, its logical and natural basis, its possible application to natural systems, its possible validation, and its possible application in watershed science and management with which this report is concerned. It is the form of a classification system, not a particular exemplification of this form in classifying, that we have the need and intention to herewith deal. More than this must be a future bringing together and ordering of empirical experience, perhaps within this form.

The form itself has an appealing simplicity and generality and will now take little effort to comprehend. Indeed, it is such simplicity and generality toward which we have been working. For, without these, we see little hope for understanding and managing watershed systems. But



this is not to say that empirical application of this form of classification will be simple: this would be to expect far too much of classification, science, and management. In later sections of this chapter and in following chapters, we will deal with these and other matters.

We have, in foregoing sections, identified four high-level, n-dimensional objects (or systems): biogeoclimatic regions, biogeoclimatic zones, biogeoclimatic watersheds, and ecosystems. We will, for our present purposes, incorporate the ecosystem level into the watershed category, where it will be retained as a means of watershed classification and management. Should such incorporation be found to present problems or lessen the power of the classification, the ecosystem category can be simply recovered. One additional sort of object for classification will be presently included: stream ecological system, the classification of which will be mainly considered in the following Chapter 7. Thus, we now have a four-level hierarchy of objects in the form of our classification: biogeoclimatic region, biogeoclimatic zone, biogeoclimatic watershed, and stream ecological system, as shown in Table 1.

Now natural objects or systems, occurring on one or another level in this hierarchy, must be separated into classes: classes of regions, classes of zones, classes of watersheds, or classes of streams. And, to do this well, we must select those characteristics of each kind or level of system that are most fundamental or essential to it and that are most invariant. What is most essential to and invariant about any natural system is its capacity, especially its potential capacity but, relatively speaking, also its realized capacity. Performances of systems, on one scale of time or another, are relatively variant: in science we want to predict performances; in management we want to control them. Performances will need to be taken into account, but they ought not to be the primary basis of classification. Else our objects would (almost continuously) be changing in class. Now the performance of a system with a (theoretically) fixed capacity changes because of changes in the state of its environmental system (Fig. 4). And the state of most environmental systems is in continuous flux: the state of an environmental system is a highly variant phenomenon. But the kind of environmental system that it is does not so readily change: environmental system kind is relatively invariant. If we think of an environment as an object (a system), even if it is an object defined relative to some (other) system, then any state of that environment is a performance of that environmental system, which must have the capacity for that performance (or state) and, presumably, an indefinite number of others. Thus, in a sense, the capacity of an environment of a system is equatable with the kind of environment of a system, and this is not only essential or fundamental to the system, it is also relatively invariant. As such, system environment, along with system capacity, becomes the second invariant basis for classification of biogeoclimatic systems and stream systems.

In Table 1, then, objects in each level of a biogeoclimatic hierarchy would be classified by their (kind of) environment and by their capacity, performances being noted only as present states of the objects. And the

TABLE 1. HIERARCHY OF REGIONAL, ZONAL, WATERSHED, AND STREAM SYSTEMS TO BE CLASSIFIED PRIMARILY ACCORDING TO THEIR ENVIRONMENTAL SYSTEM AND CAPACITIES

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I. BIOGEOCLIMATIC REGION (I)

Environment (System of Regions)

Capacity

(Performances)

A. BIOGEOCLIMATIC ZONE (IA)

Environment (Regional Class)

Capacity

(Performances)

1. BIOGEOCLIMATIC WATERSHED (IA1)

Environment (Zonal Class)

Capacity

(Performances)

a. STREAM ECOLOGICAL SYSTEM (IA1a)

Environment (Watershed Class)

Stream Order

Geomorphic Capacity

(Performances)

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incorporation principle (generalization 6) of the conceptual framework here leads to a very important result. In that systems incorporate not only their subsystems but also the level-specific environment of these subsystems, the environment of an object on a particular level of organization is (largely) the object on the next higher level of organization. Thus, as can be seen in Table 1, the environment by which stream systems would be classified is the watershed class; the environment by which watersheds would be classified is the biogeoclimatic zone class; and the environment by which zones would be classified is the biogeoclimatic region class. This, then, is the general form of the classification system we are considering.

We must now consider in more detail what sorts of biogeoclimatic performances concern us and, thus, what sorts of capacities we ought to take into account in classification of biogeoclimatic systems. Any natural system can have an indefinite number of kinds of performances, which will very much depend on how we choose to view the system and what our interest may be, as well as on the nature of the system. We do not here wish to anticipate all views, interests, and system natures and thus all the kinds of biogeoclimatic performances which may one day need scientific and management attention. Rather, here, we are concerned to identify a very few general classes of performances that will prove heuristically suggestive of kinds of performances of interest and that will subsume and thus order these kinds. We think it presently sufficient to identify these kinds of performances as being climatic performance (weather), topographic performance, organismic performance, substrate performance, and cultural performance. At the watershed level of organization, substrate performances could be soil development, surface erosion, mass wasting, water retention, and ion transfer. Similarly, as needed, the other classes of performances could be broken down into subclasses. And each qualitatively different kind of performance could occur at an indefinite number of quantitative levels of performance.

Associated with each major (and minor) kind of performance, there must be a kind of capacity for that performance. In Table 2, then, there are presented these major capacities by which biogeoclimatic regions, zones, and watersheds would be classified. It will be noted that classification of stream systems is to be based mainly on streambed morphological capacity. Development of the rationale for this will require much of Chapter 7, but, essentially, this mode of classification is to insure dimensional, dynamic, and empirical adequacy of the classification system for watershed and stream science and management.

#### POSSIBLE AND NEEDED EMPIRICAL CONTENT OF BIOGEOCLIMATIC CLASSIFICATION

Given our objectives for classification of biogeoclimatic systems and given the afore derived form of biogeoclimatic classification, what is empirically possible and what is empirically needed for an adequate classification of natural systems? We have, after all, been considering systems that are vast and diffuse in space and time, systems our theoretical

TABLE 2. HIERARCHY OF REGIONAL, ZONAL, WATERSHED AND STREAM SYSTEMS AND THE ENVIRONMENTAL SYSTEMS AND GENERAL CAPACITIES BY WHICH THESE SYSTEMS WOULD BE CLASSIFIED.

| Hierarchical System      | Environment of System | Capacity of System                                             | Performances of System                                    |
|--------------------------|-----------------------|----------------------------------------------------------------|-----------------------------------------------------------|
| BIOGEOCLIMATIC REGION    | System of Regions     | Climatic<br>Topographic<br>Substrate<br>Organismic<br>Cultural | States or<br>Structures<br>Changes in<br>States<br>Yields |
| BIOGEOCLIMATIC           | Regional Class        | Climatic<br>Topographic<br>Substrate<br>Organismic<br>Cultural | States of<br>Structures<br>Changes in<br>States<br>Yields |
| BIOGEOCLIMATIC WATERSHED | Zonal Class           | Climatic<br>Topographic<br>Substrate<br>Organismic<br>Cultural | States or<br>Structures<br>Changes in<br>States<br>Yields |
| STREAM ECOLOGICAL        | Watershed Class       | Geomorphological                                               | States or<br>Structures<br>Changes in<br>States<br>Yields |

grasp of which is very poor indeed, and systems having infinite possibilities for empirical measurement: not at all a promising picture. And yet, in a way, a great deal is known of the climates, topographies, substrates, plant and animal patterns, and human cultures over the earth. It is just that, so often, at particular places and times we do not appear to know what for scientific and management purposes we might think desirable. Sometimes, it seems, we are uncertain as to what we need to know, sometimes about what to do with what we do know. Development of adequate classification can be an aid in such instances. But there will always remain the need for appropriate empirical knowledge.

It is not here our concern to specify what the empirical content of exemplifications of the form of classification should be. Even were this our intent, it could not here be done, for this must be worked out by those who address particular systems. What we can do is treat generally the empirical problems of determining performances, capacities, environments, and maps of biogeoclimatic systems.

The problems of performance measurements are their relatively variant nature, the infinite possibilities of measurement, and the possible meanings of the measurements we do make. And, yet, performances are all that we can measure: we cannot measure operations (causal webs), capacities, or functions (rule 2, Chapter 3). We need to know what measurements, how many, and what to do with them. Vast amounts of effort are annually expended on empirical observation that will never be used or even understood. Selection and ordering of empirical experience about biogeoclimatic systems with objectives and forms of classification in mind can avoid this and yield important results. Though we have been emphasizing the variant nature of performance, some performances (states) of biogeoclimatic systems, say an expanse of prairie grass or a forest stand, move in phase space rather slowly. Measurements of these, while not the invariant base needed for classification, do provide us with an inventory of things as they are, which is one of the things needed in science and in management decisions.

Of course, the other kind of knowledge we want for science and management is what things are apt to become under various conditions. For this, we need to know something about capacities and something about environments of the systems of interest. There are, essentially, only two ways we can come to know the capacities of a system: we can determine the performances of the system under a wide range of environmental conditions, and thus indirectly observe some partial expression of its capacity (Fig. 4); or, we can learn a great deal about its operation and perhaps theoretically come to see what its capacity may be like (Fig. 3), but this approach is even more problematical for complex systems, even though it may provide some insight.

But we have displayed before us, in natural biogeoclimatic systems, vast natural and cultural experiments in space and time, if we can only see them in such a way as to take advantage of them. In a very important



sense, this is the whole point of the form of biogeoclimatic classification here proposed. Let us, for example, consider watersheds (or ecosystems, which may be simpler) within a large area of common macroclimate, zonal soils, and organismic potential for colonization. Over such an area, according to local climatic, topographic, and edaphic differences (environmental differences), different plant and animal communities will occur: together, these are an expression of the common organismic capacity of the zone. Within a class of watersheds or ecosystems, tentatively established on the basis of common organismic potential, local climate, and soils, environmental differences of natural and cultural origin will lead to different performances of particular watersheds or ecosystems (within the class), which can further establish the capacity of this class. Capacity for substrate performance, such as surface erosion or mass wasting, can be determined when the natural or cultural experiment is different levels of fire or logging leading to different levels of erosion or wasting.

The interdependency, even the circularity, of advances in empirical knowledge and classification simply cannot be avoided. Others such as Daubenmire (1968, 1978), Krajina (1969), and Hills (1961), who have developed biogeoclimatic classification systems in some respects similar to the form here being considered, have emphasized the importance of capacity and of climate, topography, substrate, and vegetation. But, for very good empirical reasons, each has tended to emphasize one aspect over others, Daubenmire and Krajina emphasizing vegetation and Hills emphasizing physiography, but in a more balanced way. The problem is measurement, measurements of weather, of soils, of things that are hard to see: vegetation and physiography can be seen. And, yet, ultimately more adequate systems of classification are needed, if they are to provide not only maps but prediction, explanation, and understanding. Furthermore, in the United States for example, public and private agencies continue to develop vast amounts of information about biogeoclimatic systems, in order to meet their responsibilities. An adequate form for classification may be of some value in guiding such efforts and in ordering empirical experience in ways to advance watershed science and management.

#### THEORETICAL AND EMPIRICAL ENTAILMENT AND USE OF A BIOGEOCLIMATIC CLASSIFICATION SYSTEM

Development of the form of classification of biogeoclimatic systems and stream systems here presented was inspired by a concern and a request on the part of the Environmental Protection Agency for a rationale for stream system science and management with respect to nonpoint source pollutants, especially sedimentary materials. Water pollution problems of this sort demand a holistic approach to any possible solution, for their origin is diffuse. In effect, we are entering, by the back door, land and cultural management as the next and perhaps ultimate phase of stream management. Perhaps this apparently sensible approach has been too long in coming. But with it will come not generally sufficiently anticipated land and cultural controls. For this, with all its implications, our theoretical and empirical knowledge may be utterly inadequate.

However this may be, it is quite apparent that entire watershed systems, and even biogeoclimatic zones and regions, must be taken into account in the science and management of stream systems. For it is on the land and in cultural systems that corrective action will be taken, not in the streams themselves. Thus, even to deal with streams, our attention must first be directed to the nature of the systems within which the streams are directly embedded, the watersheds, and then to understand the watersheds we must see them in biogeoclimatic zones and regions.

We have come to the conclusion that for dimensional, dynamic, and empirical reasons (which will be considered further in Chapter 9), formal theories and models will not soon if ever be adequate to deal with systems of this sort. Even were adequate theories and models to be forthcoming, it could only be on the basis of a very adequate system of classification. Essentially, then, our confidence has been placed in classification and the consequent ordering of accumulating empirical experience about such systems. But for a classification system to achieve important scientific and management objectives--such as we stated in the beginning of this chapter--it must have "theory-like" form and capacities for yielding prediction, explanation, and understanding. This we hope we have introduced into the form of the classification system through imposition of the conceptual framework presented in Chapter 3.

The notions of stream management by land management and land management by classification are quite generally recognized. Gessler (1975) emphasizes that the place to control stream and much river sedimentation is in the watersheds of origin of small streams, where the stream-land relationship is yet intimate and can be seen. And Hills (1961), in a most impressive display, articulates a biogeoclimatic classification of Ontario as a basis for agriculture, forestry, recreation, wildlife, and fisheries. That these and many others see this way, in one form or another, should encourage us to continue developing an adequate form and content of classification. Viable alternatives are not apparent.

## CHAPTER 7

### HABITAT CLASSIFICATION OF STREAMS

#### THE OBJECTIVES OF HABITAT CLASSIFICATION OF STREAMS

The Environmental Protection Agency has been directed to find ways of protecting stream systems from nonpoint-source pollutants, sedimentary materials being perhaps the most important of these. Even though attention is thus focused on streams, it is generally recognized that environmental management objectives for streams can be achieved only through land management practices. In a very real sense then, scientific and environmental management objectives related to streams are, rather by default, determining all else. This, of course, will not do. While we need to achieve environmental objectives for streams, very much more of interest to man is involved, including the productivity, inhabitability, and beauty of the natural and cultural land systems within which stream systems are embedded. Our scientific and management objectives for streams cannot and must not be separated from those for the natural and cultural land systems. Indeed, were they to be so separated, the objectives for the streams themselves could never be achieved, only one of the systemic reasons for this being that society would then not find the stream objectives acceptable.

The following scientific and management objectives for stream classification must, then, be kept in the context of the objectives for biogeoclimatic classification of watershed systems and how these are to be realized. Consistent with our arguments for the distinctiveness of scientific and management objectives (Chapter 1) and with our treatment of objectives for biogeoclimatic classification (Chapter 6), we will separate scientific and management objectives in the following sections, though it must remain clear that achievement of management objectives is generally dependent on the explanation and understanding made possible through the achievement of scientific objectives.

#### Scientific Objectives

- (1) Within the biogeoclimatic classification system, to order the domain of stream systems.
- (2) To provide through the ordering of empirical experience, some prediction, explanation, and understanding of the behavior of stream systems and their subsystems.

(3) To facilitate explanation and understanding of stream systems through making apparent systems, problems, general objects, relations, relative invariances, and possible approaches.

(4) To provide an ordering of stream systems that is dimensionally, dynamically, and empirically adequate for explanation and understanding.

In considering the scientific objectives for biogeoclimatic classification (Chapter 6), we pointed out that the ordering of domains and the facilitating of explanation and understanding (objectives 1 and 3) are not unusual objectives for the development of classification systems. But that the classification should itself provide prediction, explanation, and understanding and that it should then obviously be dimensionally, dynamically, and empirically adequate for these (objectives 2 and 4) are not usual requirements. And many, perhaps most, will not see these as functions of classification and within its possibilities. We, it is apparent, would be inclined to disagree with any such people, although we recognize they can advance rather convincing arguments. Nevertheless, we have intentionally so stated our objectives of classification in order to press for a form of classification that will indeed achieve more than is generally expected of classification. We think this to be necessary for adequate watershed and stream science and management.

#### Management Objectives

Achievement of the following management objectives for classification of stream systems depends not only on some achievement of the foregoing scientific objectives but also on achievement of the scientific and management objectives of biogeoclimatic classification of watershed systems.

(1) To make apparent the natural and logical connections between natural and cultural watershed events and stream events.

(2) To identify and classify stream systems according to common capacities, environments, and responses to environmental conditions including watershed resource utilization and environmental management.

(3) To provide an adequate basis for establishing stream management criteria, standards, and monitoring and the relations between these and watershed resource and environmental management.

(4) To provide an ordering of experience about stream systems that is dimensionally, dynamically, and empirically adequate for managing watershed systems so as to maintain stream systems in desired states.

With what has gone before, these management objectives can perhaps be sufficiently understood for now; further later treatment will, we think, clarify their meanings. We would only note again the ambitious nature of such objectives for classification. And it should be realized that it is not simply the abstract (form) of the classification system but also its concrete content of ordered empirical experience that will be

necessary to approach these objectives--though, in some sense, the form of the classification makes the natural and logical connections of objective 1 possible in an abstract way, which is the most general way after all.

#### IMPOSITION OF CONCEPTUAL FRAMEWORK AND DEFINITION

We have now to impose the conceptual framework and definitions to conceive of stream systems in a way making possible abduction of a form for classification adequate to our objectives. We will proceed by first considering the stream community and ecosystem, then the environment of the stream ecosystem, and finally the stream habitat system and concordance of the stream community with this.

#### The Stream Community, its Environment, and the Stream Ecosystem

As prescribed by the conceptual framework, a stream community is an organismic system extending in time as well as space from some origin through the present state to some future end, perhaps then to be followed by another community, similar or different. What we can observe is not the community but one or more space-time frames or stages of what is the entire four-dimensional continuum, the community system in the sense here to be taken.

Any biological community is difficult to bound in space and time, and this is especially so for a stream community, not so much laterally but along the length of a stream. Pertinent is the concept of Margalef (1960) that a stream community is a community succession occurring not so much through time--though this must occur too--but through space downstream. In this conception, upstream communities are the "pioneer" ones and, successively downstream, later "seral" stages export materials and organisms permitting more "mature" communities below, until in the largest river something like a climax persists. In this view, each "seral stage" in space could have its own succession in time and be a community in the sense we have intended. The stream community as a "continuum" in space (Cummins, 1977), in which transition of life forms of stream organisms occurs--relates at least trophically to the basis of Margalef's conception. Neither view provides fine enough geographic discrimination for our objectives. It is probable that we will need to restrict our definition of a stream community arbitrarily to a reach of stream of a given order (Horton, 1952; Strahler, 1952, 1957). And if such a reach should pass over more than one geological formation type, a further discrimination of communities would be required, in view of our objectives.

However we find it necessary to define a stream (biological) community, it will have coextensive and codetermined with it an environmental system extending in space and time (Fig. 1; generalizations 1 and 4, Chapter 3). This environmental system of the stream community has an indefinite boundary in space about the community as it is defined, but could not usefully be conceived as extending much beyond where the community actually is: the



water, the streambed, the banks and their vegetation, these including the components of the immediately effective and generative environment (Fig. 1) of the stream community. Together, the stream community and its coextensive environment form an ecosystem, the stream ecosystem, in space and time.

#### The Environment of the Stream Ecosystem: The Watershed

We lose conceptual and empirical value if we permit infinite regress of boundaries of the environmental system of a stream system: if too removed in space, time, and connection, something cannot be shown to affect the biological community and thus cannot be known to be in its environment. We want the stream ecosystem defined even more narrowly than this would require, because there are better means of including in our thought, representations, and applications whatever else is important. This is to say that the stream ecosystem--the stream community together with its coextensive environment--needs somehow to be placed in its own environment, wherever we choose to delimit the stream ecosystem itself. Our immediate reasons for doing so will become apparent as we develop the form of stream classification. But in narrowing our definition of stream ecosystem and in then placing this in an environmental system, the watershed, we in no way negate the kind of intimacy of relation between stream and watershed that is generally recognized (Hynes, 1975). We are only providing the conceptual structures for dealing with otherwise indeterminate phenomena.

#### The Stream Habitat System

Both our objectives and the principles of the conceptual framework now require that we make a very fine distinction if we are to achieve an adequate form of classification of stream systems. That distinction is between the sort of environmental system of which we have been writing and the sort of habitat system we now need to consider. An environmental system is a theoretical construct, the elements of which can only be poorly known, for they need to be demonstrated, one by one and in combination, to affect the organismic system of interest. A habitat, on the other hand, is the kind of place an individual organism, a population, or a community of a kind is generally found to occur. As a kind of place, a habitat is more or less superficially recognizable, primarily on the basis of gross structure: a stream is a general class of habitat and a certain kind of stream is a more specified habitat for a particular species of organism or kind of community. We see streams, and we see, or think we see, certain kinds of streams: habitat is an observational concept different from environment, which is more of a theoretical concept.

Now if habitat can be thought of as something--which presumably we must do--then it can also be thought of as an object. True, it is an object defined relative to what it is the habitat for--say a certain kind of community--but it is an object nonetheless. And if a habitat is an object having structure, that structure (that object, that habitat) must be the performance of something, and that something is what we take to be a habitat system having the properties specified by the principles of the

conceptual framework (Chapter 3). A habitat system coextends in space and time with the biological community for which it is the habitat. And a habitat system, to have a performance, a given structure or state, must have the capacity for that performance and, presumably, also for qualitatively and quantitatively different performances. But any natural system, so far as we can know or even imagine, must have its own environmental system, even if it is a habitat system or itself an environmental system. Otherwise, it could not have performances (generalization 4) and we could not know of its concrete existence. The environmental system incorporating the stream habitat system is the watershed system (generalization 6). These results derived from the conceptual framework, will largely determine the form of stream system classification.

#### Concordance of Stream Communities and Habitats

Before we proceed to abduce the form of our stream classification system, there is one further result we must derive from the conceptual framework. We are interested in the maintenance of stream communities and populations in the face of human activities in watersheds. If we were, for dimensional, dynamic, and empirical reasons, to specify in regulations only the protection of stream habitats, what assurance would we have of population and community protection? So long as stream community potential capacity is maintained--residing in other streams of the watershed and zone--there will occur over some period of time the biological populations and community that are adapted to a given habitat class. This is to say, according to generalization 5 (Chapter 3), that there will be concordance not only of performances but also of capacities of biological communities and their habitats. The form of the stream classification we can now consider depends also on this.

#### THE FORM OF HABITAT CLASSIFICATION OF STREAMS

We have now to abduce from the imposed view of stream systems an (abstract) form of stream system classification that will make realization of our scientific and management objectives possible. In the next section we will consider possible and necessary empirical content, and in later chapters we will consider validation of the form of classification, for it will not stand without this: no scientific representation can, for long. Indeed some who are interested, most especially stream ecologists who should know a great deal about such matters, will be disturbed that so much possible biological and physical measurement has been pared away from--more properly, not directly introduced into--the form of stream classification here proposed. And the reasons for their disturbance may well be found to be justified, for all conceptual constructs must be presumed fallible. But to meet our scientific and management objectives--and this seems important--we must achieve a form of classification of stream systems that is dimensionally, dynamically, and empirically adequate. Simple criteria, standards, and monitoring procedures that can be effective for thousands of miles of streams and that are socially convincing are needed. Objects of many dimensions having rapid dynamics and requiring much

measurement may justifiably be of some scientific interest. But these are not the objects by which stream systems should be classified for general prediction, explanation, understanding, and management. For these, we must develop a different sort of system for stream classification. But about one thing we must be very clear: whatever we may (at least directly) leave out or pare away (in a phenomenological sense), it is stream systems in their entirety that we will be classifying. That is to say, whatever the abstract form of the classification and whatever the empirical content, the objects of interest--those we are classifying--remain the same: stream systems, stream communities together with their coextensive environments, or stream ecosystems if you will.

The form of stream system classification we are proposing, then, directly or explicitly involves only stream system (ecosystem) environment, stream order, and stream (physical) habitat capacity, stream habitat performance being only noted, or "inventoried" as it were (Table 1). Indirectly or implicitly, both in form and in possible empirical content, the classification system covers all else that is physical and biological about streams, not only what is but also what may be: after all, as we have tried to emphasize, it is the four-dimensional stream system in its entirety that we are classifying. Such abstraction as we employ is intended only that we might do this better.

The environmental system by which we would begin our classification of a stream system is simply the watershed system within which it is incorporated (generalization 6, Chapter 3), and, presumably, this will already have been classified (Tables 1, 2). This watershed system, the environment of the stream system, determines much of the potential organismic capacity of the stream system, determines the (micro)climate of the stream system, and determines its flow regime, water chemistry, sedimentary inputs, and cultural influence.

The introduction of stream order--whether a stream is first order, having no branches, second order, formed by confluence of first order streams, and so on--is done as a matter of scaling of physical dimensions and flow regimes (Tables 1,2). This, we will see in the next section, is empirically quite important in evaluating the capacities of streams of a class. It must be recognized that the stream order concept loses much of its value if applied across watersheds of quite different classes. But this we will not find necessary.

The stream habitat capacities that we will find necessary to the form of stream system classification will be stream substrate capacity, streambank capacity, and streambank vegetative capacity (Table 2). As already noted, other habitat capacities, such as water flow, chemistry, and temperature, are more determined by the watershed system than by the stream system itself, and need to be taken into account only indirectly by classifying stream systems also by their environments, their watersheds. Finally, associated with the various capacities are the performances by which we know them: stream substrate performance, streambank performance, and streambank vegetative performance. Measurements of these are of

interest primarily to determine capacities and as inventories and to monitor for management decisions. Classification of stream systems ought not to be based directly on just measurement of stream performance, for then it would have little value for prediction, explanation, understanding, and management.

#### POSSIBLE AND NEEDED EMPIRICAL CONTENT OF HABITAT CLASSIFICATION OF STREAMS

Given our scientific and management objectives of stream system classification and, now, given the abstract form of a classification, what is empirically possible and what is empirically needed? The possibilities of empirical experience are always infinite, even if not very interesting or practical. There exists a vast literature on stream phenomena, physical and biological, the constructs of which may leave one wondering what is really understood about stream systems. The effects of sedimentary materials on stream communities including fish populations, for example, would appear not to be consistent (Iwamoto et al. 1977). This, of course, is because empirical accounts are always contingent on the conditions or context of their determination. And, very generally, these are not observed, not recorded, not made known, so there remains little possibility of ordering much, perhaps most, of recorded experience about streams. But it would be neither possible, economical, nor interesting to measure all contingencies, this only exploding (perhaps metastasizing) the information problem. For we would still be unable to understand this now even more vast accumulation of mere data. What is lacking--what is needed--is some abstract form by which all such experience can be understood and thus made a part of knowledge. And that form itself should be essentially simple in conception and application.

In proposing that stream systems be classified by their environments--their watershed classes--and by the capacities of their habitat systems, we have abstracted from the total stream system to the extent that some may be disturbed by the apparent ignoring of stream biota. But such ignoring of the biota is only apparent, for they are a part of the stream systems being classified and are simply implicit in the form of the classification itself. If the classification can be generally validated (Chapters 8, 9, 10, 11), the biotas of the streams so classified will be accounted for. But we will have achieved something very essential to our scientific and management objectives. We will have reduced, from the possible, the necessary empirical content of the classification system.

We are left, then, with the empirical problem of the habitat system: it too has an infinite possible empirical content. And, here too, we have opted for great economy: stream substrate capacity, streambank capacity, and streambank vegetative capacity. All else we have left implicit in the environmental system, the watershed class: streamflow regimes, stream chemistry, stream temperatures, sediment loads, and so on. Pennak (1971), in his classification of streams according to habitats, "found it necessary to use no less than thirteen chemical, physical, and biological items, all of which are easily measured or determined by inspection." These are



shown in Table 3. In some respects, then, he started in the correct direction. But his inclusion of several relatively variant objects (flow, current speed, temperature, water chemistry) can only lead to much measurement, more than is possible for the many thousands of miles of streams that here concern us. And no accounting of stream habitat capacity is present in the Pennak classification. Field procedures employed by the Forest Service (U.S. Dept. Agri., 1975) for evaluating stream channel stability (Table 4) come much nearer to the form that, in our opinion, is needed. So also does the stream habitat classification (Table 5) employed by Platts (1974) in his studies of streams in the Idaho Batholith.

But how do we get at stream habitat capacity, which together with stream system environment or watershed will, in our view, determine all stream system performances, biological as well as physical? In a very important sense, the answer to this question is the necessary empirical content of stream system classification. The empirical approach is essentially to view the landscape mosaic of watersheds, watershed conditions, and stream morphological states as the result of vast natural and cultural experiments, to be ordered or seen as such through the form of the proposed classification system. Thus, in arriving at the substrate, bank, and bank vegetative capacities by which streams within a watershed class would be classified, preliminary classification is necessary. A part of this classification is the watershed class of the stream, the environmental system of the stream class (Tables 1, 2; Fig. 11). Next, as noted earlier, streams within a watershed should be scaled by the stream order system (Horton, 1945; Strahler, 1952, 1957). As shown in Figure 11, this is necessary so that, within watersheds of a class, there is some scaling of stream drainage area and thus discharge capacity. And, for streams of a given order, there may also need to be classification according to geological formation. With this much preliminary classification--watershed class, stream order, and perhaps geological formation--we are prepared to see natural-cultural events as "experiments." In a series of watersheds all of the same class, different areas will be in different states as a result of natural and cultural events: plant succession, fire, logging, road building, agricultural practices, and so on. Some streams of a given order, say all third order streams in these watersheds will have been subjected to different environmental conditions. Insofar as preliminary classification by watershed, stream order, and perhaps geological formation groups streams of essentially the same capacities together, then different performances of different streams of the same capacities but under different environmental conditions (plant succession, fire etc.) will make at least some evaluation of substrate, and bank vegetative capacities of these streams possible (Fig. 11). These capacities together with watershed class would form the basis of definitive classification of stream systems.



TABLE 3. CRITERIA PROPOSED BY PENNAK (1971) FOR CLASSIFYING STREAMS ACCORDING TO PHYSICAL HABITAT

| mean width (m)<br>during 10 months                                                | 1                                | 1-5                  | 5-20                                    | 20-50                                                       | 50-200                      | 200     |
|-----------------------------------------------------------------------------------|----------------------------------|----------------------|-----------------------------------------|-------------------------------------------------------------|-----------------------------|---------|
| flow                                                                              | temporary                        | permanent            |                                         |                                                             |                             |         |
| mean current (km/hr)<br>during 10 lowest months                                   | 0.5                              | 0.5-2.5              | 2.5-5.0                                 | 5-10                                                        | 10                          |         |
| dominant substrate                                                                | rubble<br>and<br>boulders        | gravel               | sand                                    | organic or<br>inorganic<br>silt                             | coarse<br>organic<br>debris | hardpan |
| summer maximum<br>temperature, °C                                                 | 30                               | 20-30                | 10-20                                   | 5-10                                                        | 5                           |         |
| winter minimum<br>temperature                                                     | 20                               | 10-20                | 5-10                                    | 0-5                                                         |                             |         |
| mean turbidity for<br>10 clearest months<br>(ppm Fuller's earth)                  | exception-<br>ally clear<br>(10) | clear<br>(10-50)     | slightly<br>turbid<br>(50-100)          | turbid<br>(100-500)                                         | highly<br>turbid<br>(500)   |         |
| total dissolved<br>inorganic content<br>(mg per liter)                            | very small<br>(30)               | small<br>(30-100)    | medium<br>(100-300)                     | large<br>(300)                                              |                             |         |
| total dissolved<br>organic content<br>(mg per liter)                              | very small<br>(30)               | small<br>(30-100)    | medium<br>(100-300)                     | large<br>(300)                                              |                             |         |
| water hardness<br>(ppm bound CO <sub>2</sub> )                                    | soft<br>(0-10)                   | medium<br>(10-40)    | hard<br>(40-100)                        | very hard<br>(100)                                          |                             |         |
| organic pollution<br>(mean annual day-<br>time dissolved<br>oxygen, % saturation) | absent<br>(95%)                  | slight<br>(80-95%)   | moderate<br>(50-80%)                    | heavy<br>(10-50%)                                           | severe<br>(10%)             |         |
| maximum rooted<br>aquatic cover                                                   | absent or<br>negligible          | restricted<br>(10%)  | moderate<br>(10-50%)                    | dense<br>(50%)                                              |                             |         |
| dominant stream-<br>side vegetation                                               | absent or<br>negligible          | herbs and<br>grasses | brush with<br>some herbs<br>and grasses | woodland;<br>more or less<br>forested, with<br>ground cover |                             |         |

TABLE 4. DIMENSIONS EMPLOYED BY FOREST SERVICE FOR EVALUATING STREAM CHANNEL STABILITY (U.S. DEPT. AGRICULTURE, 1975)

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|             |                                                                                                                                                                                                                                                                                                                        |
|-------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| UPPER BANKS | <ol style="list-style-type: none"> <li>1. Landform slope</li> <li>2. Mass wasting or failure<br/>(existing or potential)</li> <li>3. Debris jam potential<br/>(floatable objects)</li> <li>4. Vegetative bank protection</li> </ol>                                                                                    |
| LOWER BANKS | <ol style="list-style-type: none"> <li>5. Channel capacity</li> <li>6. Bank rock content</li> <li>7. Obstructions, flow deflectors,<br/>sediment traps</li> <li>8. Cutting</li> <li>9. Deposition</li> </ol>                                                                                                           |
| BOTTOM      | <ol style="list-style-type: none"> <li>10. Rock angularity</li> <li>11. Brightness</li> <li>12. Consolidation or particle packing</li> <li>13. Bottom size distribution and<br/>percent stable materials</li> <li>14. Scouring and deposition</li> <li>15. Clinging aquatic vegetation<br/>(moss and algae)</li> </ol> |

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TABLE 5. DIMENSIONS EMPLOYED BY PLATTS (1974) IN HIS CLASSIFICATION OF  
STREAMS OF IDAHO BATHOLITH

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1. Stream, pool, and riffle widths to the nearest foot.
2. Four stream depths at equal intervals across the stream to the nearest inch.
3. Ratings, locations, and features of pools.
4. Stream channel surface material classifications.
5. Cover, conditions, and types of streambanks.
6. Channel elevations and gradients.
7. Geologic process groups and geomorphic types.
8. Stream order.

PRELIMINARY CLASSIFICATION OF  
STREAM SYSTEMS FOR TENTATIVE  
MAPPING ACCORDING TO CLASS

ON BASIS OF:

(1) WATERSHED CLASS

ENVIRONMENTAL SYSTEM  
OF STREAM SYSTEM

(2) STREAM ORDER

SCALES STREAMS AS TO  
PHYSICAL POTENTIALS

(3) GEOLOGICAL FORMATIONS

GEOLOGICAL CAPACITY  
OF STREAM SYSTEM

(4) GRADIENT

STREAM FORCE

EVALUATION OF SUBSTRATE, BANK, AND BANK VEGETATION CAPACITIES OF STREAM  
SYSTEMS BY SURVEY OF STREAMS IN SAME PRELIMINARY CLASS BUT HAVING BEEN  
SUBJECTED TO DIFFERENT ENVIRONMENTAL CONDITIONS

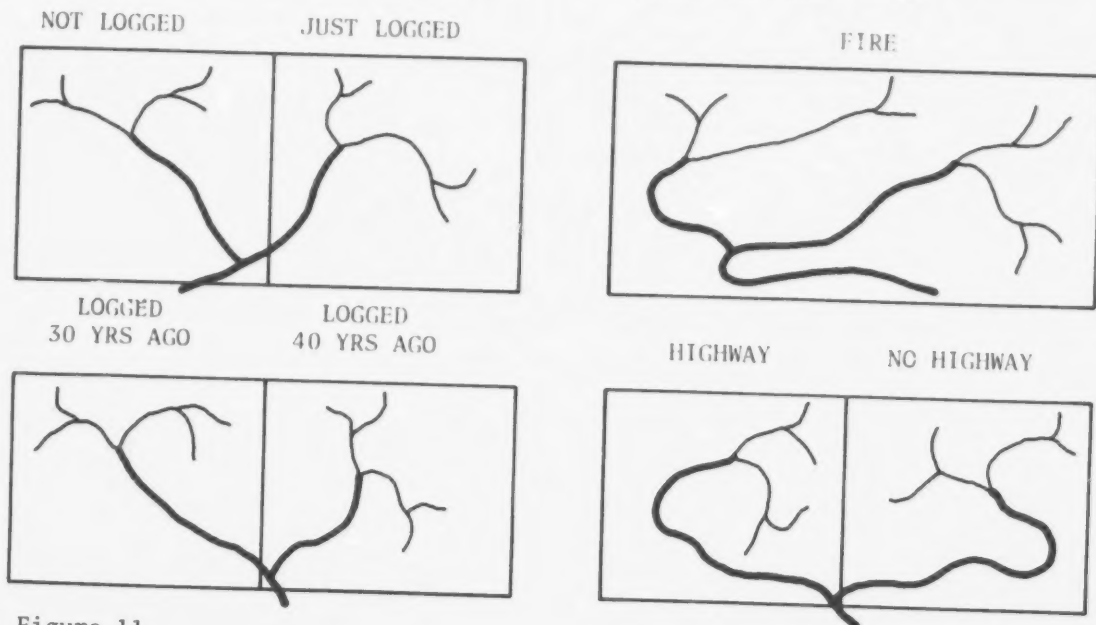


Figure 11.

## THEORETICAL AND EMPIRICAL ENTAILMENT AND USE OF A HABITAT CLASSIFICATION SYSTEM

We have achieved the dimensional simplicity and invariance of form of classification demanded by our scientific and management objectives essentially by theoretical means. That is, employment of theoretical or conceptual framework principles of environmental coextension, codetermination, concordance, and system capacity has permitted us to abstract from stream and watershed systems that which is most simple, invariant, and fundamental. And, in our view, the watershed system--the stream system environment--and the capacity of the stream habitat system determine all else directly or indirectly, explicitly or implicitly. In classifying streams according to this abstract form, we thus achieve an important degree of prediction, explanation, and understanding.

In proposing his habitat classification of streams intended to order stream systems on a world as well as more local basis, Pennak (1971) noted that: "Rather than relying on taxonomic biological criteria for a broad classification of running waters, therefore, it appears more reasonable to put the emphasis on a group of physical and chemical parameters which can be universally and easily determined, with the knowledge that widely separated streams and rivers having very similar nonbiological features will usually have parallel and ecologically similar faunas." [italics ours] Pennak here is recognizing a principle long employed in world classification of plant communities: that given similar habitats, similar plant formations (or community growth forms) will occur even though the species be taxonomically quite unrelated. It is time that stream community formations be defined, perhaps something along the lines of functional groups of insects being emphasized by Cummins (1974) and others. Streams having similar habitat system capacities and environmental systems would have similar stream community formations. These would be associated with the terrestrial biological formations or biomes of biogeoclimatic regions (Table 1).

But because of our principle of concordance (generalization 5, Chapter 3) and because, as we view it, the biological potential capacity of a system of watersheds and streams resides in their biogeoclimatic zone, classification of stream systems according to the capacities of their habitats will be predictive, over some period of time, of the species composition of stream communities, not just their formations of functional or other groups. Indeed, it is because we believe this that we feel we can recommend a watershed-environment, stream habitat-capacity system of classification for both scientific and management objectives.

The stream habitat system, in both capacity and performance, is directly coupled to the watershed system in which it is embedded. Resource utilization and management activities on the watershed, indeed whatever become so called "best management practices" must most directly impinge upon the stream habitat system, which then will determine the nature of the stream community. But the beds and banks of streams, as dynamic as they may be, are much less dynamic and much more apparent than the organisms



of the biological communities associated with them. It is our opinion that this makes them much more suited for specification of stream criteria and standards and the monitoring of these.

PART IV    VALIDATION OF CLASSIFICATION OF WATERSHED SYSTEMS

|                                                                                                 |     |
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## CHAPTER 8

### INTENTION, CRITERIA, AND PROCEDURES OF VALIDATION OF CLASSIFICATION

#### INTENTION OF VALIDATION OF CLASSIFICATION

We have now to consider the problem of validation of classification, watershed and stream system classification in particular. In doing so, we should continue to bear in mind that we do not have before us a fully specified classification system, only the essential nature or form of classification we believe to be necessary, given our objectives. Thus, we will be considering the matter of validation of classification systems having something like this form. Our consideration of validation, consistent with our treatment of form, will mainly be concerned with principles and only the most general procedural questions. In this context, it is our belief that the details will become apparent as they become necessary to those who need them in their work.

In approaching the problem of validation, we would do well to recall the nature of classification, the objectives of the form of classification before us, and the conceptual framework imposing that form. In Chapter 5, we emphasized that classification systems are both hypothetical and tool-like. As a hypothesis--more nearly, as a system of hypotheses--a classification ought to have some degree of representational adequacy for the domain it is intended to cover. And, as a tool, a classification ought to have utility. Representational adequacy and utility of a classification system are necessary for achievement of scientific and management objectives alike. Representational adequacy is determined by experience, and not simply empirical experience, about the domain of interest. So also is utility. The domain of interest to management, of course, entails the cultural as well as the "natural" and thus involves efficacy of application in management practice.

Now criteria of truth or falseness may pertain to hypotheses, but in no simple way do such criteria apply to scientific or management tools, to which utility and efficacy more directly pertain. Nevertheless, classification systems, being both hypothetical and tool-like, are of mixed nature, unlike a hammer or a saw. And if they are not in some sense valid as hypothetical systems, they are not likely to continue to be efficacious. This is to say that, unless the sufficient parameters of a classification adequately reflect causal relations in the natural-cultural systems of concern, the classification cannot be expected to be general enough and precise enough, over its intended domain, to serve its purpose. On the

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other hand, neither the philosophy nor the experience of science can support a simplistic notion of the possibility of falsifying systems of hypotheses or even individual worthwhile ones. The logical empiricist tradition has not provided an adequate account of our approach to science. Certainly complex theories, including classification systems, are not simply true or false. And the notion that hypotheses should be formulated to be mutually inconsistent, rather than complementary, has led to weak and even erroneous explanations and failure to advance understanding. We emphasize these matters, at the beginning of a discussion of validation of watershed and stream system classification, only to make very clear that we do not believe that "validation" can or should establish the truth or falsity of a classification system. Although some might like to know that scientific propositions are clearly true, any such propositions are likely to be trivial and clearly inadequate for our scientific and environmental management needs. Thus, by validation of a classification system, we mean something much more complex than establishing its approach to truth. Rather, we mean that we become more satisfied with the comprehension of the system we achieve through the classification. And, for environmental management purposes, that we are able to achieve our intentions to a greater degree than we would with any other presently conceived system. As messy as these may seem as general criteria, simpler views are likely to delude us as to the nature of the scientific and environmental management problems we face and as to the efficacy of different possible approaches. Thus, as conceived here, validation of a classification of watershed and stream systems will entail demonstration that the classification comes usefully near to its stated scientific and environmental management objectives.

#### CRITERIA FOR VALIDATION OF CLASSIFICATION

A review of the scientific and management objectives of the form of watershed and stream system classification here of concern (Chapters 6, 7) should make it quite clear that what we are expecting of classification and, thus, its necessary form are not ordinary. Indeed, what we are expecting would ordinarily be expected of a rather universal theory, not of a classification. And, in consequence, the abstract form of the classification system has a strong theoretical flavor, excepting the formal deductive structure we have, perhaps erroneously, been led to believe always can or even should characterize scientific theory. Because of the theoretical nature of the form of classification here of concern, we are faced, in many ways, with the problems faced by any who would validate a complex theory. Not the least of these problems is the partial (some would say entire) breakdown of the distinction between theoretical concepts (or languages) and observational concepts (or languages). This has made apparent that there is an inevitable circularity in attempts to confirm theory with observation. Of course, recognition of this has removed much naivete about what it is that we are doing in science. Nevertheless, because of the objectives and form of classification here of interest, criteria we might wish to apply to theory or explanation are pertinent to the validation of classification.

But before taking up such criteria, we should re-emphasize the objectives of the classification as what we ourselves expect and thus as pertinent guidelines or criteria in their own right. And in attempting to find a form adequate to achieve these objectives, we drew from our conceptual framework. We can, then, in attempting to evaluate a classification, return repeatedly to the conceptual framework, including its generalizations and rules (Chapter 3), to see how well it conforms. This may seem circular. But if the framework, in some sense, entails much or all of what we believe, no single representation abstracted from it and no simple reading of it will reveal its content: we have intentionally set it up as the way we think things can best be understood, until we have reason to think otherwise. No classification or even theory, at least in biology, is apt to be so universal.

The objectives of the form of classification here being considered are, however, couched in terms of ordering of domains, facilitating and providing explanation and understanding, unifying natural and cultural domains, and providing the basis of watershed resource and environmental management. Even though such objectives must give us some indication of our success or failure, they are not easily applied to make finer distinctions about our progress. After all, propositions that are accepted as explanations, for example, vary greatly in their adequacy. We should, then, consider criteria of explanatory adequacy, which in some sense apply to classification as a representation. Perhaps the most important of these are internal consistency, external adequacy, heuristic power, explanatory power, and aesthetic appeal. The last of these is at least as important as the others, which it probably entails. This group of criteria is probably sufficiently clear without our saying more.

Another perhaps less general group of criteria we largely made explicit in both the scientific and management objectives of the classification. These have to do with the adequacy of the classification as a representation: theoretical adequacy, dimensional adequacy, relational adequacy, dynamical adequacy, empirical adequacy, and adequacy for management. Since these expressions as criteria applied to scientific representations are adequately informative for now, we will leave some of their possible explications to Chapter 9, where we will be considering possibilities of the representational adequacy of the form of watershed and stream system classification here proposed.

#### APPROACH TO VALIDATION OF CLASSIFICATION

We will, in Chapters 9, 10, and 11, be considering the application of criteria and empirical studies to the validation of watershed and stream system classification. Here we would only note a few general matters of approach. Among these is needed maintenance of the intention to validate a classification. Validation of scientific representations is not nearly so common a concern among scientists as might be supposed, for very good reasons we will touch on below. When dealing with very mature representations, as is generally the case in physics, this is not so serious.



But immature schemes as are regularly advanced in biology, can substantially waste effort and delay advance for too long when there is little or no intention or effort to validate. We are simply saying that lapse of critical attitude, and with it creative attitude, is not unusual among groups of scientists. This ought not be allowed to perpetuate a classification or any other scientific representation beyond its real usefulness: all have limits and are, in some sense, fallible.

Validation of a (reasonably good) classification system intended to order a domain so extensive in space and time, so diverse, and in a sense so incomprehensible as that of biogeoclimatic regions, zones, watersheds, and streams can neither occur nor fail in any relatively small frame of time and space. We are, as it were, classifying the biogeoclimatic system of the earth. Validation of such a system, in any sense, can only be based on the accumulation of much experience over much time and space. Certainly special studies will be useful, and we will consider such in later chapters. But in view of the problem, the results of these are apt to be little in relation to all experience already available and that which will become available in the mere course of inventory and management of these systems in the years ahead. Especially will this be so if what is out there in these systems is viewed as a vast natural-cultural experiment, the systems, their environments, their capacities, and their performances to be ordered by classification, so that the "results of this experiment" can be seen. Failing in such ordering, it would seem, a classification is not valid. Maintenance of a critical attitude and the intention to validate during the development and application of a classification may be the best insurance we have against retaining inadequate classifications, even though we must take an extremely broad view of what is to be meant by validation.

#### CONTINUED DEVELOPMENT OF CLASSIFICATION

Suppe (1977, p. 706) notes: "When a sophisticated theory is undergoing active development, it is commonplace for scientists working on it to suppose that the present version of the theory is defective in various respects, which is to say that it is literally false, at best being only an approximation to the truth or a promising candidate; and if one is convinced this is so, it would be pointless to attempt to either refute or inductively confirm the theory. What is to the point is to use observation and experiment to discover shortcomings in the theory, to determine how to improve the theory, and to discover how to eliminate known artificialities, distortions, oversimplifications, and errors in descriptions, explanations, and predictions of reality that the theory affords. It is to these ends that science ordinarily uses data to 'test' its current theories--and not the inductive confirmation or refutation of them which has so occupied the attention of philosophy of science in the past." This could hardly be said better for the problem of validation of classification systems.

Scientists--perhaps because intuitively they have long recognized all the difficulties--are not especially interested in falsifying theories and other scientific representations. They want to use them, and to

develop new ones. Bohm (1957) emphasizes that we really do not understand a theory until it is supplanted by a more encompassing theory that clarifies the actual domain of the old theory, something that could not previously have been known. Thus, to Heisenberg (1974) relativity theory "closed-off" Newtonian theory: it defined its domain; it did not show it to be wrong or even everywhere replace it.

In a very important sense, then, whatever is developed in the form and specification of a watershed and stream system classification, it is the "closing-off" of that classification by the development of a more encompassing one that is the most possible and the most worthwhile achievement. For so long as a classification system is found more or less adequate and no other nearly so adequate is available, that classification will be used. This makes it all the more important to maintain a critical and creative stance with respect to even the most universally conceived classification, because a better one can and will be conceived one day.

## CHAPTER 9

### REPRESENTATIONAL ADEQUACY OF WATERSHED AND STREAM SYSTEM CLASSIFICATION

#### THE REPRESENTATIONAL NATURE OF THE CLASSIFICATION

Bearing in mind that we have suggested only the bare, abstract form for a classification of watershed and stream systems and that its ultimate adequacy will be determined by empirical content as well, we can still in a preliminary way consider the adequacy of the abstract representation and so introduce matters that should be taken into account in some future evaluation of a fully articulated classification. The abstract form of classification we have proposed is a hierarchical system of biogeoclimatic regions, biogeoclimatic zones, watersheds, and stream systems, each level incorporating lower ones, and particular systems on each level being classified primarily by their capacities and their environmental systems. Because the environmental system of a given level is the next higher incorporating level, the environmental systems are also primarily characterized by their capacities. We have argued, in Chapter 5, that classifications are of both tool-like and hypothetical nature and that they are conceptual devices and representations that order natural domains--Shapere (1977) would say "form ordered domains." Whatever else classification may be is not so clear. But, as we have noted, we are inclined to believe that some classifications including the one here being considered have explanatory characteristics.

In any event, we strongly believe that classifications, especially of the form here being considered, represent natural systems in ways that they can be understood. Those holding an individualistic view of the nature of plant communities (Whittaker, 1962) are inclined to believe that plant community classification is nothing but a convenience: that it says nothing about nature; that plant communities "do not really exist." With the first proposition, with regard to any well articulated classification, we must disagree. With the second proposition, who can know? It is a metaphysical statement. Yet, on this matter, Hume, Kant, and Peirce, British Empiricist, German Idealist, and American Realist could all agree: empirical experience cannot show us with certainty that what we conceive exists in reality; but, if we are not prepared to assume that in some sense and to some degree it does, we cannot understand nature; science would have no rational basis.

What is important about a classification, then, is whether or not it represents a domain in a way that we could understand it. This is

what we mean by representation adequacy, for science. For management, we need all that makes a classification adequate for science, but in addition we require that it be an adequate social tool. It is to these matters that we now turn.

#### THEORETICAL ADEQUACY OF THE CLASSIFICATION

Theoretical adequacy of a representation--always relative to what we expect of the representation--may generally entail what is essential about the existence, organization, and relations of a system: what underlies, determines, and so could explain. A very fundamental classification should entail much of this. Aspects of these theoretical qualities have been introduced into the form of the classification of watershed and stream systems by imposing the conceptual framework outlined in Chapter 3. Theoretical adequacy can, at least in part, be analyzed in terms of dimensional adequacy, relational adequacy, dynamical adequacy, and empirical adequacy, as we will superficially proceed to do.

#### DIMENSIONAL ADEQUACY OF THE CLASSIFICATION

In this and the following sections on aspects of representational adequacy, we must, of course, be clear as to "adequate for what." Adequacy is always a relative concept, and here it will be in relation to the objectives we have stated in Chapters 6 and 7. As to dimensions, we have, in these chapters, specified only the primary levels of objects and further dimensionalized these into environments and capacities, of which some possible kinds, or further dimensions, were suggested (Tables 1, 2). But as to just how these latter kinds are to be parameterized, or dimensionalized, we said little or nothing: neither are we prepared to do this nor is it conceived as the function of this preliminary treatment of the entire matter of watersheds and streams. But any definitive analysis of the dimensional adequacy of the classification would need to be based on how this parameterization as well as dimensionalization of higher levels of organization are handled. Because we cannot now do this all the way, we can only consider higher level (more superficial or more fundamental?) dimensionalization.

As to adequate for what, we at least cannot escape the feeling that scientific representations including classifications should be adequate to advance understanding. In Chapter 1, we took the position that to understand something is to see it as being essentially simple, coherent, ordered, and unified. Whether a representation is a classification, or a theory or model based on a classification, the kinds and numbers of dimensions entailed will in large part determine the extent to which this ideal is achieved. As to number of dimensions, it is always enough but no more that we ought to want. The human mind does not fully grasp, fully comprehend, or "understand" systems or representations of systems having high dimensionality. Natural systems may indeed have such dimensionality, but as we



perceive and understand them, from this we abstract to representation of relatively low dimensionality.

But to achieve adequate representation with low dimensionality, we must go to that which underlies, determines and so could explain--that which is essential to--the systems of interest. This is one of the reasons, but only one of the reasons, for making capacity one of the two primary determinants of our form of watershed and stream system classification. The other primary determinant is environment, which is also characterized by capacity (now of the incorporating system, as shown in Table 2). Entirely too often, classifications, theories, and models inadequately, if at all, treat environmental dimensions of systems of interest. It is in parameterization of capacities and environments that dimensionality can run wild, and this, in our opinion, ought to be avoided at all costs, for theoretical, empirical, and practical or management reasons.

#### RELATIONAL ADEQUACY OF THE CLASSIFICATION

We must be concerned about the adequacy of the relations hypothesized among the objects--systems and subsystems--of our classification. If we were dealing with a formal theory or model, we could note the relations imposed among its objects: whether they were deterministic or stochastic and, if so, in just what form. Ideally, we think, the form of the relations should be deterministic and even causal--between which Bohm (1957) seems not to distinguish. Nagel (1961) does make a clear distinction, as we do, between deterministic and causal-deterministic relations. But because of contingencies, we must agree with Bohm, for models at least, that a stochastic shell about a deterministic core may be necessary in direct application to nature. It is not that the contingencies themselves are stochastic in principle, because, for macroevents at least, they probably are not: it is simply that to treat contingencies deterministically the dimensionality of our representations would become virtually unlimited.

The watershed and stream system classification (Tables 1, 2) is based on hypothesized relationships much as are some theories and models. When seen as being derived from the conceptual framework (Chapter 3), this is perhaps clear enough. But were one to be presented simply with the form of classification, this would need to be analyzed into a set of propositions about objects, their capacities, and their environments before it would be clear that the core of this classification is essentially a set of causal-deterministic relations. If we were to be able to know as a certainty the capacity of, say, a watershed system and the capacity of its environment (the biogeoclimatic zone), then we would know all possible performances of the watershed and be able to account for any of them in general form. This, of course, is an ideal that neither this classification nor any theory of watersheds can ever achieve. But it is an ideal toward which the form of this classification is directed. A probabilistic shell about the deterministic core of this classification is likely to be found useful and perhaps necessary in its application. But without this core, it seems we would be uncertain as to how to proceed.



The problem of relational adequacy will relate in severity directly to how many levels of system organization must be penetrated in order to achieve a classification able to approach our objectives. If, for example, in dealing with biological community phenomena it were to become necessary to decompose communities into populations so as to represent the communities as systems of population objects and their interrelations, we would be faced with severe problems of relational adequacy. For this reason, though we may need to deal with particular populations of interest, we might be well advised, for example, to attempt to deal with communities as wholes--that is, to keep our objects at the highest level of organization consistent with our objectives.

#### DYNAMICAL ADEQUACY OF THE CLASSIFICATION

What are we to mean by "dynamical adequacy," in general and with respect to classification systems? Dynamical adequacy as generally interpreted for theories and models appears to pertain to the prediction of trajectories of natural objects in phase space. It should follow as a logical consequence of dimensional and relational adequacy. Although there is much of this in physics, there appears to be little in biology. It may be all that we can expect, and it may be enough for many purposes including our present ones, that we know tendencies in phase space and the general regions of occurrence of objects of interest. Any explanatory classification such as we are seeking must at least do this.

Another notion of dynamical adequacy, one which is made apparent in a classification treatment but not in a standard treatment, is raised by the more qualitative view of mere location of objects in general regions of phase space. This is because objects of different kinds must in general be restricted to different regions of phase space. And, when these objects are dynamic, just how far apart in phase space must they be to retain their identities? The point is this: for a classification system to be dynamically adequate, an object must not change class simply because it is moving in phase space, even if its dimensions are changing, its performances are changing, and its realized capacities are changing. These are phenomena apparent in any developing organismic system, an individual organism, a population, or a community--a particular one of a given kind. These phenomena are also characteristics of particular geological systems of given kinds. We do not want our watershed system objects to change class on the basis of such phenomena: these are evidence only of changes in system states, not changes in system kinds. And any classification that places objects in different classes simply because their states have changed would be dynamically inadequate for a watershed and stream system classification. On the other hand, should the potential capacity of a watershed system change--say colonization from a given biota were to become no longer possible--then that watershed must enter another class, a completely different region of phase space, if the classification is to be dynamically adequate.

From a practical point of view, the foregoing amounts to saying that a dynamically adequate classification of watershed systems--based on their capacities and the capacities of their environments--should permit

us to say that management practices of a certain kind have a high probability of leading to certain events in watersheds of a given class but not in watersheds of some other class. The classification will not say when such events will occur, but neither can theories and models, which will need to deal with contingencies stochastically. Still, it may for management decisions be enough to know that certain practices have a high probability of leading to certain events in watersheds of certain classes.

#### EMPIRICAL ADEQUACY OF THE CLASSIFICATION

The problem of empirical adequacy of any scientific representation pertains to the kind and degree of correspondence between the representation (which is first of all a conceptual construct) and perceptual experience. But the establishment of empirical adequacy can never be certain, because what is the representation or conceptual construct and what is perceptual experience cannot be independent, no matter how much empirical scientists would have it so. Nevertheless, we must never give up the intention to achieve whatever validation may be possible.

Certainly we must expect a classification to order empirical experience in a way that seems consistent with that experience: this, after all, is the primary function of classification. And, according to whatever else may be expected of classification, a classification as employed must be empirically adequate or sufficiently relatable to the objects under consideration. Not entirely but to a very large extent, the empirical adequacy of classifications for all their functions comes down to how unambiguously we can place objects in the different classes: Can we, in some important sense, observe and distinguish between objects of different classes? The answer to this will generally be no, if we do not classify objects on the basis of what is relatively invariant about them, their flux in space and time otherwise making them ambiguous. It is, of course, for this reason that we are proposing classification of watershed systems on all levels of organization on the basis of their capacities and the capacities of their environmental systems.

Our concern, then, comes to whether or not--better, the extent to which--we can empirically determine the capacities of watershed systems and their environments. We considered this matter at some length in Chapters 6 and 7. Now we will only note again that we can never directly and fully evaluate the capacity of anything: we can only determine performances under different environmental conditions. But, even if we only know one performance, which for observed events we always do, we know at least that much about the capacity of the system. We, at least, believe that there is little understanding of systems about whose capacities we know little. Moreover, we believe that there are nearly always ways of empirically extending our knowledge of the capacities of systems and their environments.

## ADEQUACY OF THE CLASSIFICATIONS FOR WATERSHED MANAGEMENT

Whatever else the proposed watershed classification system may be, it is intended to be adequate for watershed management, insofar as any scientific representation can be. Indeed, it was concern for stream systems and the management necessary to protect them that originally motivated the effort the progress of which is here reported. Even so, as we have persisted in arguing, attainment of management objectives of this classification in large part depends on attainment of scientific objectives: management adequacy presupposes scientific adequacy with respect to dimensional, relational, dynamical, and empirical adequacy. But, as much as this requires, it is not yet enough for management. Adequacy for management must entail knowing the responses of watershed systems to management practice--probably covered by scientific adequacy--and knowing how to specify and monitor such practices; and it must also entail legislative, administrative, judicial, and social adequacy. These matters will be considered further in Chapters 12, 13, and 14, which are devoted to application of classification to watershed management. There is, however, one fundamentally important point that we cannot overemphasize.

The classification must be of natural-cultural systems, not simply natural systems. The system of man and nature must be represented as being at least potentially concordant, not simply two impinging systems. And the classification of the cultural aspects as well as the natural aspects must be in terms of system and environmental system capacities, not simply performances, which are too superficial and too variant. In other words, we are saying that the classification is a mapping of hierarchically organized natural-cultural systems along their boundaries of potentials. We have argued that it may be possible to achieve simplicity in this way. And that simplicity is essential to human understanding. This is as so for social understanding as it is for scientific understanding. Without social understanding there will be no watershed management adequate to protect stream systems. And, for this, there must be a fabric of common sense in the classification or other bases of the management rationale.

## CHAPTER 10

### CONFORMITY OF STREAM COMMUNITIES TO STREAM CLASSES AND BEHAVIOR

#### THE INTEREST IN PERFORMANCE

Although there are many good reasons for scientific and management interest in watershed systems, much if not most of the present interest has been motivated by a concern for stream quality in relation to stream communities and populations. In attempting to develop a rational framework for the science and management of watershed and stream systems, we have embedded stream classes in a hierarchy of watershed and biogeoclimatic classes so as to ensure unification of scientific and management domains, coupling of stream systems with management units, and adequate classification of streams. We have now to examine how the adequacy of such a view at the stream system level of organization might be determined. We can think of a stream system as a whole--as an ecosystem--to be composed of a biological community (an organismic system) together with its coextensive environmental system. This environmental system includes the physical habitat system as a whole--not simply as we have dimensionalized it for classification. The physical habitat system is the environmental system of the stream community: the environmental system of the stream ecosystem as a whole is the watershed.

Now, to this point, we have emphasized the interest in the capacity of systems at all levels of organization, for what we believe to be the very best of scientific and management reasons. But this has led us to deemphasize, perhaps more than we should, the interest in performance. We must now, before we proceed, bring these two aspects of systems into better perspective. We have emphasized the capacities of systems and their environmental systems as a means of achieving general classification and understanding. The continuous spatiotemporal flux of perceptual experience of the performances of systems seems to demand that we abstract from the systems what is relatively invariant and underlies, determines, and so could explain this experience. In considering the dynamical adequacy of classification in Chapter 9, we argued that a system ought to change class if its potential capacity changes but not if only its realized capacity and certainly not if simply its performance changes. Otherwise, all biological systems and many physical systems, as we know them, would continuously be changing class: we could not identify, order, or understand them through space and time.

But we are interested in performances because they are involved in causal webs and thus in our affairs in ways that capacities are not. Were systems to have absolutely only capacities and exhibit absolutely no performances--do absolutely nothing--they could not cause anything and



we could not be aware of them: we could not even imagine them. In the present context, we are concerned with the relationships between the performances of stream physical habitat system and stream community systems as well as with the relationships between their capacities. Insofar as watershed and stream management are concerned, we want to so manage watersheds that the performances of stream communities remain in some specified (desired) areas of phase space. Certainly watershed practices that would change the potential capacities of stream communities and thus their classes are most undesirable and to be avoided. But we have intentionally so classified streams that ordinarily they will not change class, under all but the most catastrophic watershedwide changes. Thus, stream systems will almost invariably remain in a class while their performances may change greatly in response to environmental change (Fig. 4). Some region of possible performances of the communities of stream systems of a given class is likely to be judged undesirable, and watershed practices leading to the responsible environmental conditions are thus to be avoided. But what performances are to be judged acceptable and what are to be judged unacceptable must be based on relatively invariant classes of stream systems. So also must the assignment of watershed management practices, to avoid undesirable stream performances, be based on relatively invariant classes of watersheds in which the stream systems are naturally and logically embedded.

#### THE CONCORDANCE ASSUMPTION

At the stream system level of organization, we have based classification upon the environment of the stream system--which is the watershed--and the capacity of the stream habitat system, reduced dimensionally to bed morphology and composition, bank stability, and bank vegetation (Tables 1,2). We have done this to achieve dimensional, dynamic, and empirical adequacy. But for specification of desired stream system conditions in standards and for monitoring of these, all for streams of given classes, it is measurement of stream system performances that becomes of concern. And we have argued that it is the performance of a stream habitat system, as dimensionalized, that can be most reliably specified and monitored, again for reasons of relative invariance and empirical practicability. The performances of stream biological communities are extremely dynamic, are empirically difficult to adequately determine, and are difficult to interpret theoretically.

But public, legislative, administrative, and biological concern appears to have been primarily about the stream community or, even more narrowly, especially about fish populations. In the long run, it can be argued, our attention might better be focused on maintenance of physical habitat for, so long as the potential capacity for biological colonization is maintained in the biogeoclimatic zone, maintenance of the stream community is assured. Stream physical habitat may require geological time for repair; biological communities only successional time, under the conditions specified.



In any event, it is the stream system as a whole--the stream ecosystem--and beyond it the watershed and the biogeoclimatic system with which we ought really to be concerned. At the stream system level of organization, we are proposing to deal with this concern by classification of streams according to their habitat system capacities and by specification of standards and monitoring on the basis of habitat system performances. This reduction to bare physical dimensions is intended to provide for biological communities and populations of interest. The rationality of this intention and approach is based on our assumption that there is present and probable future concordance between the capacities and performances of a biological community and those of its coextensive environmental system (generalization 5, Chapter 3). This is to say that we believe--that we assume and are willing to act accordingly--that the capacities and performances of biological communities follow those of their environments in a certain harmony and law-like agreement. Otherwise, communities as we are able to know them would not persist.

This is not to say that such concordance assures the persistence of the community kind or community state that we for our own human reasons may wish. In "following along" in harmony and agreement with its environmental system, a biological community of a given class may reach states or performances we do not wish maintained. What we are arguing is that measurement of the performances of the habitat system, so long as colonization potential is maintained, is a reliable way of determining what sorts of community states can be expected. Desired communities will conform to habitats that themselves become desired for this reason. But this is all based on the concordance assumption. Validation of this classification at the stream level of organization becomes, essentially, validation of this assumption.

#### STREAM COMMUNITY ENVIRONMENTS, CAPACITIES, OPERATION, AND PERFORMANCES

Biological communities are among the most difficult objects man has chosen to study and understand. There is presently little understanding of biological communities: indeed, it is not at all clear that communities can be understood, at least according to the ideal of being comprehended as essentially simple, ordered, and unified. Among communities, those of streams are perhaps more easily sampled than some others, are perhaps more difficult to define in space, are more dynamic in structure than most, and are seen with others as having high dimensionality and a degree of hierarchical structure. We ought to approach such objects with considerable care of intention and method.

In Chapters 3 and 4, we went to some length to define a community as extending in time from some original state up to an through the present state to some terminal state (Fig. 1). Coextensive in time and space with such a community would be its environmental system. And, in these chapters, we carefully distinguished between the capacity and the performances of a system as a whole. In succeeding chapters, we then built our system of classification and its validation and use on the distinction between environmental system, the system of interest, its capacity, and its

performances. But we have not, as yet, made many judgements on any use of the concept of operation of a system, which we defined in Chapter 3 as the interactive performances of successively lower levels of organization that lead to performances of a system as a whole. And it would be at some hazard were we to proceed with discussion of study of biological communities without some consideration of the concept of operation.

An operational explanation of the performance of a system is an internal causal-web sort of explanation. In rule 2 (Chapter 3) we stated that only the performance of a system or subsystem can be measured, its capacity and its operation being representable only indirectly and incompletely. In modified form, this is only to say that we do not observe causes, much less causal webs. Convinced by Hume's demonstration of this, Kant with a transcendental argument tried to show that causation, along with space and time, is an apriori principle of human understanding. However universal and necessary causation may be to understanding, it would be difficult to argue against the importance of its role. But what must be made clear here is that, while we may be able to observe an indefinite number of performances on successively lower levels of system organization, we do not observe operation. Rather, we order such observed performances by writing an operational--or causal web--representation onto the system of interest; indeed, we thereby form the system of interest.

We have digressed on this matter of operational explanation because of the almost unlimited possibilities for operational explanations of communities, which have untold levels of organization, numbers of species, and kinds of relations. Indeed, the possibilities are so unlimited and the task of representation and confirmation so vast, one might wonder if operational explanation of communities is the "black hole" of ecology. Of course we must continue to seek ways to make communities understandable operationally and in other patterns of explanation. And we must do this with stream communities as with others. But, for purposes of stream classification, its validation, and its application through standards and monitoring, we would be well advised to emphasize performances of stream communities as wholes and those of populations of particular interest, as well as their abstract capacities and environments. Stream community processes--operations--are much more dynamic, more variant, than stream community performances such as structure, change of structure, and persistence, which are sufficiently variant to plague us enough. Such performances are the relatively slowly moving outcomes of rapidly moving processes or operations at lower levels. Ultimately, we do want to understand their internal causes. But for our present purposes, to show conformity between stream habitat systems and biological communities, we want more to work with that which is relatively less variant.

## THE CONFORMITY OF DYNAMICAL COMMUNITY STRUCTURE TO STREAM CLASS AND BEHAVIOR

The structure of any biological system, including biological communities, is a performance of the system as a whole. As such, structure is an outcome of the developmental and maintenance processes of any biological community. Habitat and environmental changes much influencing community development and maintenance are likely to lead to observable changes in community structure. Moreover, through evolutionary and other ecological adaptation of community processes, the structures of communities tend to be adapted to and characteristic of their particular habitats and environments. Thus, classes of community structures should conform to classes of a properly conceived and developed habitat classification of streams. And changes in habitat system performances or structure within a given stream class should be followed by characteristic changes in community performance, community structure now being of interest. In validation of the classification of stream systems by habitat capacities and its application to management through habitat performance measurements, it will be necessary to establish conformity of stream class and behavior with community structure and its change across a wide range of stream system classes and environmental changes.

In modern ecological thought, it has become commonplace to define community structure as "the pattern of resource allocation among the species of a community, and their patterns of spatial and temporal abundance" (Cody and Diamond, 1975). However adequate such a definition may be for certain areas of ecological thought, it will not do for our present need to validate conformity of classes and behavior of community structure with stream habitat classes and behavior through extensive surveys of many classes. This is because, even if resource utilization by all species in a biological community could be adequately conceptualized, it certainly cannot be empirically determined for any but a few relatively simple communities. Accordingly, for our purposes, we will define community structure as the species composition and relative abundances in a community through time and space. Even for this definition, the empirical difficulties of determination for many communities should in no way be underestimated. It will be recalled that we have suggested a rather carefully specified classification of stream systems according to their watershed class (the capacity of their environment), the capacities of their beds, banks, streamside vegetation, and the sequential order of the stream (Tables 1, 2). Even were a stream system in such a class to be in its most persistent stage, when the plant community of the watershed has reached a climax stage, changes in community structure seasonally and with spacial habitat differences can be very great and must be taken into account. Few kinds of communities can be or have been sampled so adequately as those of small streams. But this has shown the dynamic--the variant--nature of stream community structure. Stream communities do not have the long persistent determinants of terrestrial community structure, the trees and shrubs and grasses. Stream community structure is evidently more dynamic than terrestrial community structure but less dynamic than plankton community structure.

Diversity indices of various sorts have been formulated and employed to describe community structure and changes in community structure with changes in habitats and environments, including those caused by man. For some very restricted purposes, such community diversity indices may be an economical, convenient, and useful representation of community structure. But the best diversity indices require essentially the same information as does the determination of species abundance relations. And May (1975) has recently and convincingly demonstrated that all diversity indices are poor representations of community structure as compared to species abundance relations. Species abundance relations are represented in various ways. One useful and easily visualized way is to rank species according to their abundances along an abscissal axis and plot their relative abundances along the ordinal axis. Inclusion of taxonomic information in the species abundance relations would bring them into conformity with our definition of community structure. This should increase their value as a means of determining conformity between stream class and behavior and community structure. Here we ought not, we think, be too interested in or dependent on the mathematical formulations of species abundance relations. On careful reading of May (1975) and Patrick (1975), one comes to the conclusion that they have little of theoretical interest in application to stream communities, and perhaps less than has been supposed for other kinds of communities. There may be one interesting use of reducing such information to a diversity index. If an adequate index to habitat diversity can be formulated, there should be a good correlation between community diversity and habitat diversity. And this should be a causal relation, because reductions in habitat diversity are likely to lead to reductions in community diversity. This would be one of the major effects of sedimentation of otherwise rough stream bottoms.

#### THE CONFORMITY OF COMMUNITY ORGANIZATION TO STREAM CLASS AND BEHAVIOR

In our definition of community structure we did not include patterns of resource utilization as has become common in much recent work in animal community structure. We did this so as to leave structure a more or less directly observational concept: species composition and relative abundances. When we begin to include relationships between objects in a system, other than simple spatiotemporal ones, as we do when we introduce patterns of resource utilization into a definition of structure, our concept of structure is no longer an empirical one. Rather, we have written onto a system an operational organization determined in very large part by how we choose to view the system. We should do this. But we think it useful to distinguish clearly between spacio-temporal structure of kinds of parts and the operational organization of parts of systems. For the broad surveys necessary to determine stream community conformity to stream class and behavior, a simple observational view of structure and its determination will be most helpful. We cannot expect to determine, on a survey basis, much about the organization of many different stream communities.

Yet there remain important scientific and management reasons for understanding the organization of stream communities. Organization is



both a developmental process and a state of that which has developed, and both meanings should be entailed in our view. Organization is a "theoretical" construct written onto a system, a community in the present instance, which defines "organs" at different hierarchical levels, the kinds of relationships among these, and what their operational explanations and functional roles within the community may be. Community organization, in that it develops, is in some sense a community level performance, but not one so directly observable as structure.

Biological communities are so complex as to make their organization perhaps conceivable and yet not imaginable (Loneragan, 1958). If we take understanding to be comprehending a system as being essentially simple, ordered, and unified in some sense, then it is not at all clear that communities are understandable. Even so, understanding of communities should be the goal of community ecology. The problem is to so conceive of communities that they can, in principle, be understood.

In our view, a community is an organismic system and is organized just to the extent that it conforms to the six generalizations we advanced in Chapter 3. In particular, subsystem concordance and the incorporation of subsystems along with their environments reflect the degree of community organization (generalizations 5, 6). Interpretation of the organismic system diagram in Figure 3 may help to make visualizable the notion and importance of incorporation. But even such a general view of organization as set forth by this set of generalizations is written onto the system as a means of understanding and may say as much about us as it does about the system of interest. Kant knew this must be so. Our task, then, is always to find ways of so ordering things as to make nature most comprehensible.

Within some such overall framework, communities are organized according to various aspects of their subsystems. Life history organization, that is, concordance of the life history patterns of the species in a community may be most essential to its organization. Habitat organization, how the different kinds of places species live are interrelated, is another important aspect of community order. Trophic organization, the patterns of nutritional resource utilization, has received most attention, to the detriment of a balanced view, but is, of course, fundamental. And, then, there is a theoretical organization that subsumes these and is achieved through the interrelations of the environments of community subsystems: environmental organization.

The "functional group" representations of stream communities proposed by Cummins (1975) ) and his co-workers is an example of conceiving of complex systems in a way that may make them more amenable to understanding. Stream ecologists have come to realize the importance of terrestrial sources of organic material, primarily leaves, in the economy of small stream (Hynes, 1975). This organic material is processed from coarse to fine particulate material and finally to dissolved substances. According primarily to the size of "particles" they process and their means of obtaining these materials, stream organisms have been classified as being "shredders," "collectors," "grazers," and "predators." It has been proposed that in the "continuum" of systems and change from small streams to large rivers, these functional groups change in their



relative abundances in characteristic ways, shredders being most abundant in small streams, collectors of fine particulate matter being most abundant in rivers (Cummins, 1977).

Organisms are classified into such "functional" groups, irrespective of their taxonomic kind or relations. The simplification and view achieved permits some understanding. It may provide some insight into how stream communities might be classified according to "form," as is done in classifying plant communities into plant formations--forest, grassland, etc.--irrespective of the species of plants present. Such a classification of stream communities could provide a means of relating them to the plant formations of biogeoclimatic regions of the world. But correspondence of "functional groups" of stream organisms to stream class and behavior should be taken as complementary to and not a possible replacement of community structure in terms of species composition and abundance. We must continue our interest in protection of species of life and kinds of communities, not simply kinds of performances.

We have introduced this much on community organization not only to emphasize its importance but also to give some indication of the difficulty and means of understanding it. Most current community study is apparently directed at community organization, as it should be. But studies of community organization--by this very nature, if they are good--are not easily adapted to broad synoptic studies of the sort that may be necessary to soon establish conformity between stream communities and stream classes and their behavior.

#### SCIENTIFIC AND MANAGEMENT INTEREST IN COMMUNITY CONFORMITY TO STREAM CLASS AND BEHAVIOR

On the choice of facts, Poincare (1913) in "Science and Method" states that "Method is precisely the choice of facts." In responding to Tolstoi's assertions that science for its own sake is an absurd conception, that facts are infinite, and that we would be better guided by utility than by mere curiosity, say about the number of ladybugs on our planet, Poincare argues that all this shows a profound misunderstanding of science. Scientists believe in a hierarchy of "facts" ordered by the most simple ones, which are the most universal, the most general and invariant, and likely to be the most abstract. Scientists ultimately do not study nature because it is useful but because it is beautiful in pure ordered conception and they delight in it. But just here Poincare performs a marvelous inversion of his argument: since what is simple reappears again and again in things, since man can only understand what is simple, and since he can only use what is general and what he understands, the simple that scientists seek primarily because it is beautiful and delights them is that which ultimately has the most utility. In the twentieth century, there has been a display of this belief of Poincare.

This insight of Poincare into the relations among the objectives of science, the motivation of scientists, and the practical affairs of men

informs us about the scientific and management interest in community conformity to stream class and behavior and to the need for simple and universal knowledge of streams. Stream communities are many, diverse, complex, and in constant flux. We cannot understand them, as ecological science ought to do, except as we can determine what is general and relatively invariant about them, what underlies, determines, and so could explain this flux of unordered, complex perceptual experience. Taken apart from their biogeoclimatic and habitat systems, environments having biotic and physical capacities, there is no way of understanding communities. And, even in their diverse and complex environmental settings, communities are not to be understood except as these can be simply ordered. Moreover, from the content of communities themselves must be abstracted that which is simple, universal, and understandable.

Of scientific interest, we believe the form of the hierarchical classification of biogeoclimatic, watershed, and stream systems is of the sort to make the environments of stream communities comprehensible. This, we believe, is a much needed step in so ordering stream communities as to make them understandable. We may be able to show conformity of stream community structure to stream class and behavior. This should in some degree confirm our account of stream community environments and such understanding as this makes possible. But with the organization of the communities themselves, we have dealt only very generally and abstractly. While such a general conceptual framework is an essential step in the understanding of community organization, it is our belief that there have yet to be made important advances in the theoretical and empirical dimensionalizations of community organization capable of dealing adequately with entire communities.

There will be ultimate management interest in adequate understanding of stream community organization, but such understanding as presently exists is both theoretically and empirically inadequate as a basis for evaluation and monitoring of watershed management practices. It is in part for this reason that we have based the form of our classification of streams on their morphological capacities and the capacities of their environments (watersheds) as well as on their numerical order. This is a relatively simple, general, and invariant view of stream system classes. Within classes, the phase space behavior of stream morphologies must be monitored on a broad scale over many years. Should stream community structures be shown to conform not only to stream class but also to such stream behavior, we will have achieved a valuable management tool before we will have achieved an adequate understanding of stream community organization. But, for the reasons so eloquently stated by Poincare, scientists will continue to seek ways of understanding community organization and, to the extent they are successful, there is in this scientific and management interest.

## CHAPTER 11

### CONFORMITY OF FISH POPULATIONS TO STREAM CLASSES AND BEHAVIOR

#### EMPHASIS ON PRODUCTS OF INTEREST

There are often very good reasons for placing emphasis on system products of interest, and, for stream systems, fish populations are good candidates for this. Such interests may be both scientific and practical, and we will sketch some of these considerations. But, in adopting a product of interest approach for either scientific or management purposes, we must be careful that we do not focus so simply on some product, say a fish population, that we fail to account for it adequately in terms of its environmental system and in consequence fail to achieve either scientific or management objectives. Unfortunately, this is the history of fisheries science and management. But those involved in other domains of the science and management of natural resource and economic systems have little reason to suppose their performance has been much superior in this. In considering emphasis on products of interest, then, we must stress not only the need for this but also the need to avoid its pitfalls.

Any time we approach a complex system of any sort, we are, in either a scientific or a management sense, confronted with the problem of how to deal with it. Are we to study the entire complex system by means of a few high-level sufficient parameters? Or are we to attempt to represent the entire system operationally in terms of performances of many of its subsystems? Or are we to focus on some one or a few subsystems and study them intensively? In our opinion, there are grave difficulties with each of these general options, and as programs for science and management they have generally, for these reasons, been not very successful. Perhaps such a judgment is based on expecting too much. Which of these options is to be adopted ought to depend on carefully stated objectives, and maybe these objectives should be scientifically and in terms of management more limited than we have been inclined to make them. In any event, scientifically we may go to a lower level of organization, say a product of interest, a fish population, because we are indeed most interested in that level of organization. Or we may do so because we want to achieve a certain theoretical and empirical adequacy in some investigation and believe we can best do this with a simpler system, though we would better think of it simply as a system at a lower level of organization and not delude ourselves that it is "simple."

There is a certain practical reason--better, a pragmatic reason--for management emphasis on products of interest. So long as we account adequately for, say, a fish population, we ought to be able to manage it in the context of perturbation of its environmental system: that we have not generally been successful in doing so perhaps attests more to the inadequacies of accounts than of the inaccuracy of the proposition. But emphasis on products for management interest has another practical reason of a particularly pragmatic sort. That part of the general public interested at all in stream systems will mainly be interested in fish populations. A pragmatic reason for emphasis on fish populations is that such emphasis may "work": scientific programs, standards, and enforcement based on products of interest can be more easily sold than can programs based on some vague community or ecosystem conception. Personally, we are very uncomfortable with such pragmatics--with its almost cynical tone. That it may achieve protection not only of the product of interest but also of the entire system producing that product is a possible and important result: we would yet remain uncomfortable with the basis of this result, that the ends justify the means, essentially James' pragmatic criterion of truth as being what is useful. Far better it would be that society could come to know that any product of a system, most especially natural systems that we cannot rebuild, are best protected and provided for by maintaining the system entire. Although there has been an encouraging increase in awareness of this principle, we have yet a long way to go and, somehow, natural systems ought to be maintained.

All this may seem rather far from our immediate concern of establishing conformity of fish populations, or products of interest, to stream classes and behavior. But we think it not. Mere conformity may be mere association--if in nature there be such--and thus an ephemeral relation of little scientific interest or management value. Perhaps as we have envisioned the establishment of conformity of stream community and population performances with stream classes under different environmental conditions over years, any established conformities would be most unlikely to have only probabilistic bases. That is, they would seem to need to be based on causal-deterministic cores. One problem, it would appear, is that contingencies across many kinds of systems and within systems of particular kinds would so obscure any causal-deterministic core that we would be left, if with any, only a probabilistic pattern. We are extremely uncomfortable about science and management based on probabilistic patterns alone, without any apparent causal-deterministic core. Perhaps it is for this reason that we are inclined to encourage--even in the validation of a watershed and stream system classification--at least some studies that are more than synoptic in nature, some studies that attempt to establish causal-deterministic relations among fish populations and dimensions of their environmental systems. We would hope that the complexity of this need not enter systems of standards and monitoring to control watershed management but rather that it would provide insight into how more adequate simple dimensionalizations are to be achieved.



## FISH POPULATION CONFORMITY WITH HABITAT AND OTHER REQUIREMENTS

Let us begin with the premises that there will be conformity of a species population of fish with its habitat and other environmental requirements so long as colonization has occurred at some time in the past, and that conformity will occur in the future so long as the capacity for colonization is maintained in the watershed or the biogeoclimatic zone. This is simply a particular interpretation of the principles stated in generalizations 4 and 5 of the conceptual framework we are employing (Chapter 3). Were something very near to this interpretation not to prevail, we could not understand the distribution and abundance of even very thoroughly studied species populations. And, fundamentally, our system of watershed and stream classification and its application to science and management are based on these principles and their interpretation. The degree of conformity of fish populations with stream classes and their behavior will depend on how adequately this classification and its dimensionalization reflect nature.

It will be recalled that stream system classes, according to the form of classification here proposed, are to be based on stream order, streambed morphological capacity, streambank stability, and streambank vegetation capacity as well as on the capacity of the environment of the stream system, which is the class of watershed system within which it is embedded (Tables 1, 2). Now of the environmental requirements of fish, only streambed and bank morphology might be made explicit in this form of classification: this could amount to the dimensionalization and representation of streambed materials, stream gradient, pools, riffles, shelter, and so forth. But other habitat and environmental requirements of fish populations are at least implicit in the classification system. This is to say that patterns of stream discharge, temperature, and water chemistry are functions of the watershed or environment of the stream system, and streams are to be classified by their environments as well as by their morphological capacities. But fish must live in a biological world as well as a physical world. And their trophic or nutritional environment is a part of this. Even the trophic environment of fish populations would be implicit in the stream class, for it includes streambank vegetation, which by shading determines light and by leaf and other debris fall may form the basis of the stream nutritional economy. And the food-web organisms of the fish are implicit in the classification in that their potential capacity for colonization resides in the biogeoclimatic zone and watershed.

There is yet another aspect of the biological environment that must be considered, especially before the results of certain fish habitat studies can be made more generally applicable. There has been considerable recent interest in defining the physical habitat requirements of particular species of fish, say as to the size and condition of gravels in which salmonids might spawn, the depths and widths of streams in which they occur, the current velocities, riffles and pool combinations, and so on (Bovee and Cochnauer, 1977; Bovee, 1978). But it must be emphasized that, no matter how important such information could be, it is not specific to



species and habitat characteristics alone but is also determined by all other dimensions of the environment, including ones we have already noted. Especially, the occurrences of fish species in particular habitats is determined by what other species of fish are present as competitors and predators. Thus, we are again confronted with the problem of how to achieve scientific generalization and effective application to management in the face of contingencies. Information on habitat requirements of fish, based on distributions of fish, is of limited scientific and management interest without the occurrence of other species being taken into account.

Habitat partitioning among fish species in streams and how particular species distribute themselves both in the presence and the absence of other fish species is presently receiving some of the attention that it merits. Some of the most interesting recent advances in ecology have resulted from similar studies of birds (Cody and Diamond, 1975). What is becoming quite clear is that species populations are likely to narrow their range of habitat occurrence in the presence of competitors and predators. Here again, we need studies not simply of community and population system structure but of their organization as well.

What, then, are we to say about the possibility of scientifically interesting and practically useful conformity of fish populations to stream class and behavior? Perhaps only this: conformity to class will occur to the extent that all determining environmental dimensions of the species of interest are explicit or implicit in the classification of stream systems; conformity to stream behavior within a class will occur to the extent that habitat and biological conditions in the environment are actually adequately dimensionalized. The scientific and management interest in habitat requirement and partitioning studies of fish is much dependent on the embedding of such studies in biogeoclimatic zone and watershed system classifications. Synoptic studies may demonstrate some conformity of fish populations to stream system class and behavior. But we can, initially at least, expect this conformity to be rather poor, because of contingencies. Thus, in the development and validation of an adequate classification system, we will need detailed studies such as those on habitat requirements and segregation, in order to provide enough understanding of the causal-deterministic core, from which we may be able to abstract sufficient parameters for effective synoptic employment.

#### REPRODUCTION, DEVELOPMENT, GROWTH, AND BEHAVIOR OF FISH

The occurrence of a fish species in some stream habitat is direct evidence that, for some part of its life history, environmental conditions there are more or less suitable. But mere occurrence does not indicate the degree of habitat and environmental suitability or that all phases of the life history are being provided for at or near a location. One of the advantages of focusing some attention on a product of interest, say some fish population, is that we then may have the opportunity to

develop a more adequate explanation of its occurrence, its distribution and abundance. Important in any such account would be knowledge of reproductive, developmental, growth, and behavioral responses to known environmental conditions in streams of particular classes and states. Only responses of this sort can be taken to indicate, for individuals of a species, the environmental suitability of particular habitats and stream classes. And this information is important in explanation of population structure, production, and yield, matters to which we will turn in the next two sections.

We must be concerned with establishing the adequacy of environmental conditions in particular stream habitats and classes for the entire life history pattern or trajectory of species of particular interest, or for that part of the pattern ordinarily occurring in such habitats and classes. In this, reproduction and development are of special importance. Indeed, consistent with the conceptual framework (Chapter 3), we take development of an individual organism to be sequential changes in its realized capacity and thus a process that occurs throughout the life of the organism, not simply prior to reproductive age. Thus, in assessing the adequacy of environmental conditions for development, age at reproductive maturity and other later developmental responses should be employed along with the early ones we may still wish to give much emphasis. These early developmental responses are in time, place, environmental condition, and relation to parents closely associated with reproduction and in many studies are scarcely distinguished, the nature of reproduction or reproductive success covering events until juvenile developmental stages are reached. Thus, studies of environmental conditions necessary for successful salmonid reproduction should pertain to spawning events as well as to all of those occurring in streambed gravels until the young emerge as fry. Environmental conditions during the period of development to reproductive maturity are of considerable interest and have not generally received as much attention as have those associated more closely with reproduction and early development. But this later period is critical to reproduction, as unfavorable conditions can delay reproductive maturity or decrease reproductive success in other ways.

Studies of the growth of fish, either directly by measurement of known individuals or indirectly by scale and stock analysis, are very much a part of fisheries science, are not particularly difficult, dominate the literature, and are not of much interest except as results are related to environmental conditions. For some populations, the difficulty of associating environmental conditions with the growth response perhaps make it not surprising this has been done poorly or not at all. But failure to relate growth to environmental conditions in other instances is more evidence of poor use of time or judgment. In streams of the size here of concern, it should nearly always be possible to obtain information on temperature, abundance of food organisms, and other environmental conditions determining growth. It will not always be possible to obtain simple relationships between these conditions and growth. But between streams of different classes and with much difference in quality of conditions within classes,

differences in environmental conditions are likely to be sufficient to lead to clearly apparent differences in growth patterns.

Reproductive behavior, territorial or other competitive behavior, feeding behavior, protective behavior, and migratory behavior are responses of individual organisms to environmental conditions and determine the success of their populations. The behavior of fish is not usually easy to observe and it is never easy to study so as to relate it to environmental conditions. Even so, such studies ought not to be neglected in the development and validation of a system of watershed and stream classification, one of the purposes of which will be to provide for fish populations of interest.

From a practical point of view, even from a biological point of view, we are interested mainly in the persistence of populations of fish, not individual fish that reproduce, develop, grow, and behave. Thus individual responses, are involved in determining the persistence, structure, and production of populations and are essential to understanding these population responses. But the population exerts powerful influences on individual organisms by determining many of the conditions of their environments: interaction among individuals, food availability, disease transmission, and so on. Without much distinction as to just how these population influences are brought about, they are often subsumed under the notion of density-dependence: that is to say, individual responses of reproduction, development, growth, and behavior are in large part determined by the numerical or biomass density of the population. Thus the cumulative outcomes of density influences on individual responses become apparent in population responses such as structure, change in numbers or biomass, production, distribution, abundances, and movements. Not only to understand the individual responses, but also to understand their relations to population responses, it is essential to relate reproduction, development, growth, and behavior of individuals to the density and general status of their populations.

Conformity of these individual responses with stream class and behavior must provide an important part of the causal-deterministic core by which any conformity of fish populations to stream class and behavior would be made apparent. During development and validation of a watershed and stream classification system, some studies of this core should probably be conducted in streams of different classes and states. Such studies are not at all suited for broad-scale application in standards and monitoring. And, even in the development and validation of classification systems, these studies ought not to be undertaken lightly, because if they are to be done adequately they will be difficult and generally useful results will not soon be forthcoming.

#### POPULATION STRUCTURE OF FISH

Let us define the structure of a fish population as its magnitude in numbers or in biomass together with the distribution of numbers or of

biomass according to age classes as well as size classes of individuals. Population structure, so defined, is a more or less directly observable performance of a population as a whole. And population structure, as here conceived, should be distinguished from organization, for essentially the same reasons and in much the same way as we distinguished between community structure and community organization in Chapter 10. Populations have distinctly organismic patterns of organization, extending from the genetic level upward to social subsystems. Such organization in large part is the concrete expression of the potential or capacity of a population. But its representation is far more a feat of conception than observation, unlike structure as we have defined it.

Although structure is clearly a performance of the population--only a population could have population structure--it is an outcome of the reproductive, developmental, growth, and behavioral responses of individual organisms to their environments. This is to say that structure, as a performance of a population, can in principle be operationally explained in terms of the reproductive and other performances of individual organisms, these lower level performances forming the "inner causal web" leading to population structure. Although anything like full understanding of population structure would require such accounts, we cannot generally expect to have them and must usually get along with more superficial explanations. This is not to say that, even in development and validation of a classification system, studies of reproduction, development, growth, and behavior should not be undertaken. Rather, it is to suggest that we cannot, for all streams that must be considered, conduct detailed investigations at this level of organization. And, even when this is done, the results will not always be adequate for operational explanations of population structure.

But operational accounts of population structure are not generally necessary for us to gain some insight into the responses of a population as a whole to environmental conditions. We can by comparing population structures at different times in the same stream, and at the same and different times in different streams, learn how population performances in streams of the same and different capacities vary in response to various combinations of environmental conditions. Indeed, so long as we on other bases establish different streams to have the same or similar capacities, we can begin to evaluate these capacities by obtaining sets of different performances under different environmental conditions (Fig. 4). But short of this, we can still, on a comparative basis, gain some insight into what sorts of streams best support fish populations of interest and what environmental factors tend to degrade this capacity of stream systems.

The analysis of population structure is rather highly developed in fisheries science (Ricker, 1958). And the possibilities of taking advantage of this methodology should not be overlooked in studies of stream populations. On the other hand, at least for the smaller streams with which we are likely to be concerned in watershed and stream classification and management, much of this methodology is largely irrelevant. Streams of this sort do not have large populations and, as environments, are extremely variable. Population enumeration can usually be based on nearly complete



removal of a population. Even so, the small size of such a population and the variable conditions of its environment make classical methods of estimation of vital statistics inadequate. We can, however, by an examination of age structure, gain insight into success of reproduction, variability in reproduction and survival, and longevity under different conditions and in streams of different classes. And the magnitude of populations is of great interest in understanding the capacities of streams of different classes and the effects of different environmental conditions on the capacities of streams of the same classes. It must be emphasized, though, that great care must be taken in obtaining adequate information on relevant environmental conditions, for this is not always or even usually done. One of the factors that should be taken into account is fishing intensity, which has important recognizable effects on population structure. In many of the smaller streams (first and second order) here of interest, fishing may be virtually absent or of very low intensity.

#### STREAM SYSTEM PRODUCTIVITY FOR FISH

Over the past four decades, there has been great interest and a tremendous amount of work in trophic (or nutritional) ecology--the consumption and utilization of energy and materials throughout the "food webs" of biological communities. But in spite of this interest and effort, and regardless of the sometimes enthusiastic treatments in textbooks and journals, the theoretical and empirical results are almost uniformly disappointing, especially at the biological community level of organization. This should probably have been expected, because the theoretical problems of dimensional and dynamic adequacy and the empirical problems of measuring energy and material utilization of hundreds of species are enormous. For these reasons, it is not conceivable that detailed trophic relations of stream communities can be employed to demonstrate conformity of stream community classes to stream habitat classes. The picture is somewhat more encouraging for dealing with the capacities of streams to produce particular species populations of interest, especially for larger animals such as fish, which are usually empirically more tractable. But even studies of stream productivity for fish must be very substantial undertakings, if the results are to be reliable and sufficiently general to be useful. It is to be seriously doubted that adequate studies of productivity for fish can be conducted in enough different stream habitat classes to directly demonstrate conformity of productivity and habitat class. On the other hand, it is quite possible that theoretical and experimental investigation coupled with field studies can, to some useful degree, demonstrate which physical habitat parameters and how prey organism densities and interspecific competition among fish are involved in determining stream system productivity for particular species of fish of interest.

Now production is a performance of a population and ought to be distinguished from the capacity of an ecosystem, say a stream system, to produce this population. The capacity of a system to produce a population



of interest we think is best termed its productivity (for that population). But the important thing is the distinction between performance and environmental capacity, between production of a population of interest and the capacity of a system to provide for this. We emphasize this because it is commonplace not only to use the terms production and productivity interchangeably, which is permissible, but also to confuse two different concepts, which has led to erroneous thinking in studies of production and trophic relations. The importance of the distinction between population production and (environmental) productivity, or capacity as we shall define it, will become apparent.

Production of a fish population is a performance of the population as a whole and can be defined as the total elaboration of tissue in a given period of time, regardless of the fate of that tissue. For a population composed of individuals of a single age class, production (P) can be represented and determined as the product of mean population biomass (B) and mean individual relative growth rate (G) over a rather short period of time, say two or three weeks.

$$P = G \times B$$

The production values determined over short intervals of time are then summed algebraically (including any negative values occurring when mean growth rates are negative) to determine the production value for the total time period of interest. Other methods of calculating production yield essentially equivalent results (Chapman, 1968). If a population consists of more than one age class, production values should be determined separately for each age class and then summed to obtain the population production value. It is quite possible, with sufficient care and effort, to obtain adequate estimates of production of fish populations in small streams (Warren et al. 1964). The effort involved is, however, such as to make prohibitive the estimation of production values on a large number of streams that could be involved in studies of watershed and stream system classification. There are also problems of explanation and interpretation of such production values as are obtained.

Let us consider a population having a single age class, to take the simplest possible case. So long as stream system productivity were to remain constant and food resources were to be limiting, an increase in the biomass of a fish population would lead to a decline in the relative growth rates of its individuals. Production, being the product of biomass and relative growth rate, would first increase to some maximum and then decline toward zero as biomass of the population increased. Such a curve of production in relation to biomass can be thought of as defining a single level of stream productivity, or realized capacity for producing that fish population (Fig. 12). Were a higher level of productivity to have prevailed as population biomass increased, then a higher and wider curve of production would have been defined, and so on (Fig. 12), there being an indefinite number of such theoretical curves. We see, then, that production is a function of stream productivity as well as of population biomass. And any determination of production has much less interest than has been commonly

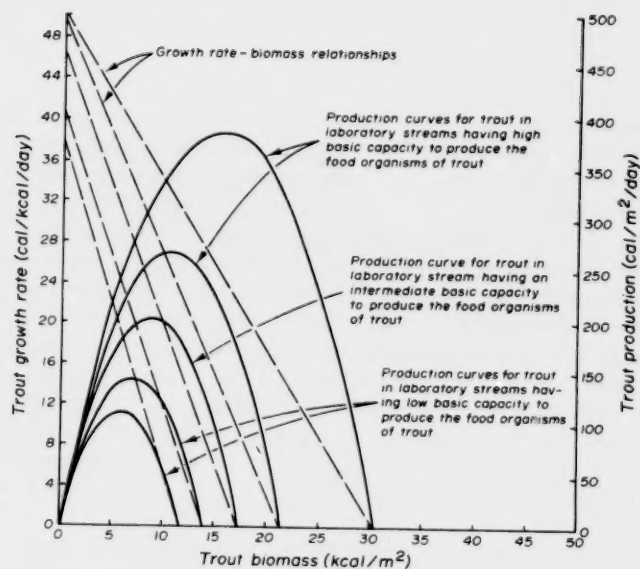


Figure 12. Biomass-growth rate curves and the biomass-production curves derived from them at different levels of productivity. (After Warren, 1971).

supposed, a change either in biomass or in productivity, both of which change continuously, being sufficient to change production (Warren, 1971). Were we to be able to determine production values across a range of biomasses, while productivity remained constant, then we would have some notion of what this productivity was, something no single measurement of production can tell us. Unfortunately, it is stream productivity in which we are most interested: what its dimensions are and how it changes with changes in environmental conditions such as stream physical habitat.

We can deduce theoretically the dimensions of productivity. And, through laboratory stream experiments, experimental stream channel studies, and intensive field studies we can learn how sedimentary and other alterations of these dimensions influence stream productivity and thus fish production and, if the populations are exploited, yield to man (Liss, 1977). Perhaps this much we must do, in order to establish clearly how environmental changes in watersheds can, in principle, affect stream system productivity. Such understanding can be immensely helpful to interpret the status of fish populations as these are influenced by sedimentary and other environmental changes in stream systems in different classes and states. But it would be erroneous--and could result in much wasted effort, lost opportunity, and wrong conclusions--to suppose that determination of a performance so dynamic as fish production can be accomplished and meaningfully interpreted over many streams of different classes as a means of establishing fish population conformity.

PART V APPLICATION OF CLASSIFICATION TO WATERSHED MANAGEMENT

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## CHAPTER 12

### RESOURCE UTILIZATION PRACTICES, WATERSHED RESPONSES, AND STREAM HABITATS

#### THE ENVIRONMENTAL PROTECTION AGENCY, STREAM PROTECTION, AND RESOURCE UTILIZATION PRACTICES

Under directives of Public Law 92-500 the Environmental Protection Agency has assumed the role of instituting means of control of so-called "nonpoint-source" pollution of streams and rivers. It is apparent that means of control of nonpoint-source pollution will, in general, need to differ from those for control of pollution originating from more or less clearly distinguishable sources. Indeed, it is probably correctly perceived that control of some of the major sorts of nonpoint-source pollution will need to entail the regulation of land management practices. Somewhat less directly, as in pesticide registration and air pollution control, the Environmental Protection Agency has for some years been involved in determining land and urban management. But in the adopting of the expression "best management practices" as a means to protect stream systems there is clear acknowledgment of what may now be entailed in the regulation of pollution.

Recognizing the need for dealing with the general problem of stream pollution of diffuse origin, the need to deal with the problem by improved land management, and the need for a national effort in this, one can still have some concern about the implications of a single federal agency determining land management policy for the nation. There is the need for a rationally planned and administered program of land management, for land resource protection as well as stream protection. And splintering of land resource management responsibilities among many federal, state, and private agencies has not provided adequately for land resources and universal--general and long-term--public interest. Yet we must always maintain concern about centralization of authority, about the relatively more limited understanding and competency within any single institution, and the possibility of serious consequences. More adequate land management appears to be the most rational way to proceed in stream protection, and land resources are in their own right at least as important and in as serious need of attention as are stream resources. The Environmental Protection Agency, with some understandable reluctance, has been committed to land management via stream management--via, as it were, the "backdoor." However necessary and desirable resultant programs may be, socially this may not prove to be the best basis for involvement.

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Then again, within the limits of a democratic society, just how agencies become involved is perhaps secondary to the imperative that our society and all others must develop more rational natural-cultural systems. If better stream resource protection demands better land resource management and can so be achieved, society will benefit immensely. If authority centralizes in a single agency or flows out from that agency, we must insure that the agency has the diverse intellectual, material, and governmental resources necessary to its task.

#### THE MEANINGS OF BEST MANAGEMENT PLAN

The natural resources of a country are, in the most fundamental sense, a national property, whether held by the public or the private sector. It cannot be otherwise for a society to persist in a natural-cultural system. There is, as it were, a "social contract" on this, a contract that becomes apparent through governmental activity intended to enhance the public interest. As it pertains to natural resources, the notion of best management plan presumably is based on there being the possibility of knowing what is the universal public interest. By universal public interest, again, we intend to signify the general, invariant public interest, all aspects of a society over all time, ideally for all societies. Unfortunately a much more restricted view of the public interest has nearly always been adopted in the past, in many instances with disastrous consequences. Determination of a best management plan should then entail prior determination of the universal public interest.

Now this is scary: we don't like to entrust such matters to others, as we to a considerable extent must do, even in a democratic system of much size. But so long as best management plans are to be considered and instituted, it is best that we be clear about what is really entailed in the public interest. Management of the Nation's resources has been in the public interest only in the limited sense that vast amounts of resources have been made available to be used by most of our people. Even recognition that there might be a universal public interest not synonymous with present public interest appears to be relatively recent and not very general and not at all generally acted upon. But, even in the present context, it has generally been presumed that what is in the best interest of primary producers of resources is in the general public interest. That this is not so and that much of the public no longer accepts it as being so is now apparent.

This brings us, then, to the question of management plans best for what and whom? We are here concerned with stream systems and all that they mean to a society. Are the best management plans to be instituted to be best for maintenance of stream systems in some desired series of states? Is this what we mean by "best management plan?" How does the public interest in fishes, food, or even recreational access to fragile natural systems relate to this? And what about the forest, agricultural, or other resources of the watersheds in which the stream systems are embedded? Of course, in some "appropriate proportions," all interests are to be taken into account: it is only rational! But this is the old

"multiple-use" concept with dominant-use riders by which all sorts of abuses of the universal public interest have occurred. All this may seem very obvious, but it is not a problem that has been squarely faced. There will be real difficulty in determining what the universal public interest may be, in determining which among many alternative management plans would be best for this, and in getting social acceptance of programs so based.

#### ESTABLISHING CAUSAL RELATIONS AMONG WATERSHED PRACTICES, RESPONSES, AND STREAM HABITATS

We pretend to a great deal of understanding when we propose to manage natural-cultural systems. We are assuming that we correctly perceive societal interests and goals and that they are good, that we know the causal-deterministic core of relations, that we can manipulate the major determinants, that contingencies will not make ineffective our efforts, and that society will support these efforts and accept the results. Perhaps agriculture in the United States, even with all its difficulties, comes reasonably near to appearances of a rationally managed system. The record of management of other resources of the United States is much more mixed. Present exploitation of forest resources in many third world countries is a tragedy, little or no attempt being made to apply what is known, even by participating developed countries. In contrast, our present concern to so manage watershed systems as to maintain suitable resource yields along with the quality of stream systems is an almost unimaginable ideal. Yet, it is one toward which much progress can certainly be made.

In order to recommend, for a certain class of watershed in a certain zone and region, management practices that will result in certain resource yields and anticipated future responses as well as generally acceptable conditions in its stream systems, we must know relations between those practices, watershed capacities, responses, and stream conditions. Indeed, if we are to have much confidence in recommending practices, the relations of concern should be of a causal-deterministic sort, even though contingencies will introduce some stochastic behavior. Now science establishes causality in systems mainly by experimentation, in which the systems are "closed" and in other ways simplified and idealized. Generally only then are causal connections made clearly apparent. There have been forest watershed experiments of rather large scale that have established important causal relations among watershed practices and subsequent events (Likens et al. 1970). Out of such studies has come understanding that will help us to perceive more clearly the important relations in watersheds not so intensively studied: that is the function of experimental studies. But never could we hope to study examples of all classes of watershed in their various zones and regions of the country. Yet, somehow, if we are to manage rationally all such systems, as apparently is presently being proposed, then we must know, for all of them, the essential relations. With less than this, we would indeed be pretending.

Now it must be made very clear, before we continue, that a very great deal is known about agricultural systems and much is known about

grazing and forest systems. Indeed, it is primarily from what is now known about agricultural and forest technologies and their effects that best management practices for regions, zones, and watersheds will need to be established in the near future. The difficulty in this is that what is known is so largely unordered that we are uncertain as to the limits of generality of known relations between practices and their effects. It is precisely here that a universal system of classification based on the capacities and environments of watershed systems and biogeoclimatic zones and regions can advance our understanding and management potential. Such a classification system, written onto the landscapes of the United States, can so order past experience with and present states of watershed systems as to make all this a vast experiment. This can then be interpreted as to the kinds of practices most likely to provide for resource utilization as well as stream quality in watersheds of different classes in their respective zones and regions. But, largely for lack of adequate observation and records, this may be sufficient to distinguish only between very good practices and very bad practices, a broad range of practices being indeterminate. And, for these reasons, about many classes of watersheds we may be able to make practically no judgments.

Once a classification system of the sort we are considering can be written onto all our national landscapes, then more adequate information must be obtained on practices, watershed responses, and stream conditions, all ordered according to classes in the hierarchy based on the capacities and environments of the systems. Because, at any time, a rather large number of watersheds will occur in most classes and these will be subjected to different practices (until practices are specified) information of an experimental sort will accumulate rapidly over a relatively few years. This, of course, only if there is general and consistent application of some adequate classification system. Otherwise, it is difficult to see how sufficient experience and ordering of experience is to occur to make possible the specification of best management plans for the many watershed classes in the zones and regions of this country.

Consistent relations among watershed practices, watershed responses, and stream habitat conditions in watersheds of a class will be strong evidence of underlying causal-deterministic relations. The form of classification here considered and the way in which it is dimensionalized will help to make apparent the relations that are likely to be causal. The importance of knowing the "reasons" for things, when we need to anticipate sequences of events, should then encourage us to look much more closely at those relations supposed to be causal to see what justification there may be for such a stance.

#### CLASSIFICATION FOR EXPLANATION, PREDICTION, AND MANAGEMENT

We have suggested, then, that only by ordering what does and will amount to vast empirical experience with watersheds of all kinds under all kinds of environmental conditions does there appear to be much chance of determining best management plans. It has been our contention that such

ordering would be effective only under a classification of the general form we have considered. Such a classification could, in effect, turn human experience with watershed systems into a vast experiment having an indefinite number of treatments and replications for watersheds of the various classes.

The "natural experiment" function of classification we did not consider directly in Chapter 5, where we dealt with the nature and uses of classification. But this function--this making apparent large-scale natural-cultural "experiments"--is a consequence of the way in which this form of classification so orders natural-cultural phenomena as to provide explanation-like relations among capacities, environments, and performances of watershed systems of various classes, matters we did consider in Chapter 5. And, we have argued in succeeding chapters, such a classification--because of the way in which it could order and explain--should provide some prediction of the course of events following perturbation of watershed systems of given classes, not precise prediction, which our best models cannot provide, but prediction of sufficient precision and reliability for sound management decisions, which our models may not provide.

In the next two chapters we will be applying the classification system to management with all its problems. As will become apparent, it may be necessary but it is not sufficient for management that a classification system be scientifically adequate. In some important sense the classification must also be socially adequate for management. Many of the characteristics of simplicity, order, and unity that make for a good scientific representation favor social suitability. The form of scientific understanding and what constitutes common sense may need to approach one another in socially adequate management systems.



## CHAPTER 13

### BIOGEOCLIMATOLOGY, SOCIOLOGY, TECHNOLOGY, AND THE ENVIRONMENT

#### CONCORDANCE OF BIOGEOCLIMATIC, SOCIAL, AND TECHNOLOGICAL SYSTEMS

The various biogeoclimatic regions, biogeoclimatic zones, and even watershed classes of the United States have characteristic patterns of forestry, agriculture, mining, and other resource utilization, because of their natural capacities and historic patterns of sociological, economic, and technological development. These patterns of resource utilization are environmental inputs or factors of the watersheds and other natural systems here of concern. Such resource utilization practices interact with the capacities of watersheds to determine their responses, which may include environmentally undesirable ones as well as desired levels of resource yield. In some cases, mainly in agriculture, the patterns of resource utilization that have developed are concordant with the capacities of the watersheds and have thus led both to desired and sustainable levels of resource yield and to only minor undesired environmental effects. But this is likely to occur only when a very long and enlightened view is taken of resource utilization and potential environmental effects. Essentially, concordance of resource utilization capacities and performances with the capacities and performances of the watershed system has been achieved when this occurs.

On the other hand, when shorter and narrower views of resource utilization have been taken, sociological, economic, and technological pressures have been allowed to cause nonconcordance of watershed practices and watershed capacities. Almost invariably this will lead to lower levels of resource yield and undesirable environmental effects. Some of the undesirable watershed responses will, in turn, be causally related to parameters of stream habitats and change these in ways likely to lead to undesired changes in stream communities and populations. There are the best of reasons for seeking concordance of resource utilization patterns and watershed capacities, regardless of stream habitat outcomes, in order to sustain desired levels of resource utilization and other environmental conditions. But the legislative directive to the Environmental Protection Agency is to insure desired stream conditions. Thus, it is of the utmost importance that causal relations between resource utilization practices, watershed responses, and stream habitats be clearly established. For if this is not done, it is to be seriously doubted that sociological, economic, and technological pressures will permit the necessary general acceptance of stream habitat standards and their enforcement.



## SOCIAL AND TECHNOLOGICAL PERTURBATION BY ENVIRONMENTAL REGULATION

How and to what extent scientific, resource utilization, and environmental problems are perceived by scientists, by those directly involved in provision of resources, by those utilizing these resources, and by all concerned with these and other aspects of the human environment are very much determined by local as well as global sociological contexts. There has quite recently, in only some cultures, developed an environmentalist sociology. No matter how important some aspects of this sociology may be locally and globally, presently and for the future of man, this environmentalist sociology is generally only a superficial overlay of a sociology of fundamental human needs and approaches to their provision. This latter sociology pertains directly to where and in what way people live and eat, and this is more immediate and universal than more recently articulated environmental concerns, although both are continually subject to changing culture and attitudes.

But when environmental management, no matter how well conceived, dictates changes in fundamental sociological or cultural practices, there will always be difficulties of acceptance and effectiveness. Prevailing technologies and economics are a part of this sociology and they will generally be re-enforced by the other parts. When environmental management seeks to alter deeply ingrained cultural practices, as occur in agriculture and to some extent in forestry, acceptance and effectiveness of this management are likely to remain in doubt for some time. This must be understood, accepted, and worked with for environmental management to achieve its objectives and be consistent with persistence of a sound system of resource utilization. Environmental management of watershed systems, to be accepted and effective, must take into account local as well as national sociological structures, in addition to the nature of the natural systems of concern and the technologies and economics of resource utilization.

## TOWARD SOCIAL, TECHNOLOGICAL, AND ENVIRONMENTAL CONCORDANCES

As already noted, there have developed for the various biogeoclimatic regions, biogeoclimatic zones, and watershed classes of the United States patterns of resource utilization that are presumably economically acceptable. But this economic acceptability has very often been premised on a short time frame and present technology. And there has been very little assurance that over longer time frames sociological, economic, technological, and environment concerns, as well as resource yields, will continue to be acceptable. Indeed, all too generally, this is not even presently the case. In any event, it is not generally the case that alternative management practices are presently given very serious or extensive consideration, unless economic and, more recently, environmental considerations have made this mandatory.

Now insistent environmental legislation, even in the absence of adequate knowledge, has changed all this. And the effectiveness of alternative management practices in maintaining desired environmental conditions must be determined. At the outset, it must be kept in the forefront that

the management practices presently in vogue are, and alternative management practices must be, characteristic of regions, zones, and watershed classes. It cannot be otherwise, because other practices are not likely to be effective in sustaining desirable levels of resource yields and maintaining acceptable environmental conditions. This, of course, is the fundamental reason that administratively dictated patterns of watershed management for desirable sustained levels of resource yield and acceptable environmental conditions must be based on a suitable hierarchical classification of biogeoclimatic regions, biogeoclimatic zones, and watersheds.

Among extant watershed management practices, some are undoubtedly acceptable and some are undoubtedly unacceptable for reasons of resource yield and environmental conditions. Throughout the different regions of the United States, and associated with the various watershed classes, there must be determined by survey and analysis which extant management practices are acceptable in terms of resource yield and environmental conditions. Such acceptable practices should be instituted by regulation. For all other extant management practices, alternative ones must be formulated and tested. This is a vast problem and the results of formulation and testing, however correct, are going to have profound effects on resource utilization and yield and on environmental conditions in this country. There is a very large probability, almost a certainty, that some ill-conceived and inadequately tested watershed management practices will be instituted by regulation, this leading to undesirable resource management, utilization, and yield, as well as to undesirable environmental effects. This, of course, must be avoided insofar as is humanly possible. Those most knowledgeable in the agriculture, forestry, and biogeoclimatology of a region must be deeply involved in developing management plans to be instituted.

## CHAPTER 14

### ON A RATIONALE FOR WATERSHED MANAGEMENT TO PROTECT STREAM SYSTEMS

#### ON PRELIMINARY SPECIFICATION OF ALTERNATIVE RATIONALES FOR WATERSHED MANAGEMENT

In Chapter 2, we suggested that a rationale is an argument for doing something in a specified way. It is an explanation or exposition of controlling principles. From its root meaning, we ought to expect a rationale to be rational, but our definition would not insure this. Indeed, though we must seek universal standards of rationality, there must inevitably persist a certain relativity, which can be good or lead to evil. We introduced certain problems of rationality in resource and environmental management in Chapter 2, and we have been concerned with these problems throughout this report. In the next section, we will highlight them in the form of criteria for rationales for watershed management.

Now, we would only note that rationales must be fully specified for determination of their rationality to be possible. Unfortunately, this is simply not done, at least in anything like an adequate way. To be able to judge as to the rationality of a practice, one needs to know its suppositions, its objectives, the understanding on which it is based, and how its effectiveness is to be counted. Thus, in Chapter 2, we set forth in general form the needed content of rationales for resource and environmental management. There we suggested that specification of a conceptual framework, objectives, a classification system, criteria, practices and standards, administrative institutions, procedures, and guidelines, evaluation procedures, and procedures for correcting institutional and other weaknesses would be essential to any such rationale. Most of these matters we have dwelt on at considerable length through this report. In the form of a preliminary rationale, we will bring them together in a following section. Before proceeding with the matter of criteria for rationales, we would make only one further point. What follows is intended to be but a preliminary specification of a rationale for watershed management, and it most certainly is no more than this. In making the entire process of resource and environmental management rational, there are good reasons for specification of preliminary rationales, for early evaluation and for what guidance they can give to research and management planning. Furthermore, it is not just one preliminary rationale, like this one, that should be specified. Rather, several equally carefully worked out but alternative

ones should be made available for scrutiny; none will be fully adequate but only in this way can the most adequate be determined.

#### CRITERIA FOR DEVELOPING AND EVALUATING WATERSHED MANAGEMENT RATIONALES

Fundamentally, criteria for developing and evaluating watershed management rationales ought to insure that a selected rationale is indeed rational. That is, the criteria themselves must entail broad elements of rationality, not narrow specifications that could eliminate unusual and yet, in terms of rationality, the best conceived approaches to watershed management. We have, then, to first complete our consideration of rationality itself.

Let us begin with a definition: rationality is that which makes understanding possible. There must be, we would think, three fundamentally different kinds of human understanding. Pure logical understanding would be that which we have in unapplied mathematics, geometry, and symbolic logic. Phenomenal understanding is understanding of the nature of natural and cultural systems including man. And humanistic understanding is that sort of understanding which leads to continuous improvement of human relations within each man, among men, and among men and their biological and physical environments. This last sort of understanding, beyond that quality of a person "being understanding" and so acting, must include much else of what we take to be civilization, including satisfaction of human physical, social, creative, and intellectual needs. Humanistic understanding, cannot, however, be a mere extension of phenomenal understanding. Though humanistic understanding may employ what phenomenal understanding is available, phenomenal understanding does not necessarily lead to humanistic understanding. Yet, in a sense, it is the task of a rationale, say for watershed management, to unify phenomenal and humanistic understanding pertinent to this problem. Rationality would seem to demand this. But it is not well exemplified in the story of civilization.

As to understanding itself, let us extend Maxwell's (1974) view. To understand something is to be able to comprehend it as being essentially simple, ordered, unified, harmonious in role and, thus, as being essentially beautiful and good. Rationality, then, is what makes this possible in the logical, phenomenal, and humanistic domains of understanding. We will treat, only in the broadest form, criteria of completeness, rationality, bestness, and common sense, really all matters of rationality, as these pertain to rationales for watershed management.

#### Rationale Completeness

In everyday and in scientific communication we achieve considerable mutual understanding in our accustomed domains because of commonalities of conceptual frameworks, languages, and values. In such communications, most of the argument and message is left implicit, and necessarily so, or communication would break down under the burden. Nevertheless, rationality and mutual understanding may be more assumed than real in much communication: we get by on the assumption that we are rational and



understand. Generally, this is not a matter of great moment. But there are such matters, and resource and environmental management happen to be among them. Rationality must be made as certain as can be. A first condition of rationality of an exposition is that it be explicitly complete for informed public scrutiny, our primary test of rationality.

It is, then, of the utmost importance that rationales for watershed management be complete. Already in Chapter 2 and again in beginning this chapter, we have indicated some eight or so classes of items such a rationale should perhaps contain, but the form of a rationale could alter this. Still, whatever the form, most any rationale ought to contain an explicit conceptual framework elaborating the view of the natural-cultural system that is being assumed. Then, always, goals and objectives must be made clear. The approach being taken and the basis in understanding for this should be specified. Also, how success is to be evaluated. Finally, any rationale that is rational should contain the basis for its own orderly change, even replacement, should circumstances so dictate.

#### Rationality of Rationale

We are concerned that an adopted rationale ensure the proper use of phenomenal understanding in achieving as much humanistic understanding as possible, where humanistic understanding entails that which makes possible continuous improvement of human relations. And according to our notion of understanding, this would be possible only if a rationale provided for comprehension of the natural-cultural system of concern as being essentially simple, ordered, unified, harmonious in role, and thus, beautiful and good.

If we begin with something like Peirce's concept of good as that which is right for all men over all times, we can see that a rationale for watershed management should be an attempt to insure the persistence of these natural-cultural systems over indefinitely long periods of time in series of states that provide for human needs. These needs include physical and biological resources, but not these alone. For a fully rational management system must provide for human aesthetic needs as well, our view of rationality entailing beauty, and not being unusual in this.

Another criterion of a rationale for watershed management must be social acceptability. No program of a pluralistic and democratic society can be pragmatically rational without a high degree of social acceptability--it simply would not work. This raises perhaps the most difficult problem of all: how is it to be ensured that what is socially acceptable in a particular context is good as a general matter? It is on this issue, of course, that societies eventually fail through either insufficient resources or insufficient human understanding. Much depends on a society's being enlightened and humanistic: at a minimum, rationales must inform.

A more mechanical aspect of the external adequacy of a rationale has to do with its applicability. That is to say, rationality demands



that a rationale make clear under just what circumstances and in just what ways its various parts are to be applied to the natural-cultural systems of concern. In a sense, this has to do with the unification by a rationale of phenomenal understanding, humanistic understanding, and the natural and cultural domains to which they pertain.

Finally, as Stephen Toulmin (1972) would argue, rationality resides not simply in logical structures such as rationales but in the very processes by which understanding is advanced through change. A rationale, to be fully rational, must have a certain stability; but it must also have the capacity for self-correction, or it will become an impediment to meaningful resource and environmental management. This is only too well known.

#### Rationale Best Among Alternatives

In a sense, no rationale is fully rational so long as a more adequate one can, in the same context, be articulated. This, of course, is difficult to know. Nevertheless, it may not be rational to adopt a rationale except as it can be shown to be the best among alternatives that have been equally fully and carefully developed. To insure broad assessment of the possibilities of watershed management, the development of alternative rationales out of markedly different conceptual frameworks should be encouraged.

There would remain, however, the exceedingly difficult task of determining the best rationale among alternatives. For any rationale conforming to the criteria we have already advanced will have a high degree of internal consistency and external adequacy: in short, it will be highly rational. We are, as it were, left without a place to stand in making high level judgments among already rational alternatives. What now is the framework? We can suggest only that humanistic understanding, maintenance of the capacity of natural-cultural systems to persist, and provision of aesthetic as well as physical and biological needs--in other words, that which is most good, beautiful, and rational--are beyond particular conceptual frameworks and even cultures. Still, it must be admitted, as abstract and severe as these criteria may be, their application can hardly be absolute--not relative to context.

#### Common Sense of Rationale

Every effort must be made to insure that at least the most directly concerned elements of society perceive a rationale for resource and environmental management as entailing little more than common sense. Such is not too general a perception of governmental activities. And, of course, these activities thus lose in social acceptance and effectiveness. Again, however, we have the problem of relativity, now relativity in what is the ordinary understanding. In short, this may not always or even usually be good and beautiful, immediate self-interest playing too dominant a role.

There is, nevertheless, much that would be perceived as common sense in our definition of understanding including its notions of simplicity, order, unity, harmony, good, and beauty. In providing rationales

judged best against these very fundamental criteria, we may be coming as close as possible to what enlightened critical common sense may be like.

## A RATIONALE EMPLOYING CLASSIFICATION FOR WATERSHED MANAGEMENT

In Chapter 2, we suggested eight general topics with which a rationale for watershed management should deal. Now, on the basis of arguments developed in this report, we intend to articulate the general form and give some indication of content of a rationale for watershed management that would entail a large degree of rationality. In doing this, we will address in sequence each of the eight general topics earlier raised.

### (1) Conceptual Framework of Rationale

The rationality of a rationale can not be fully evaluated unless the conceptual framework upon which it is based has been made explicit. Such frameworks entail our presuppositions and determine our problem perception, objectives, approaches, and what we take to be satisfactory solutions. Even so, they are rarely made explicit, and much failure of scientific and management understanding and even ordinary communication results.

The conceptual framework proposed in Chapter 3 emphasizes the four-dimensional nature of any natural-cultural system of interest, three dimensions in space and one in time. Co-relative and co-extensive in space and time with such a system is its environmental system. We know of systems by their performances. But these are determined by the capacities of the systems together with their environments. Performances of systems are relatively more variant than are their capacities, which also change with development. In a very important sense, it is the potential capacity of a watershed system that must be maintained. It will be maintained--the system will be adapted to its environment--so long as there is concordance between not only the performances but also the capacities of the watershed system and those of its environmental system including man. It is such concordance that a rationale for watershed management should insure. Watershed systems are one level of organization in a hierarchy of systems extending downward from regional and zonal biogeoclimatic systems through watershed systems to even lower level systems such as the stream ones here of special interest. In this hierarchy, higher level systems incorporate not only lower level systems but the environments of these as well.

### (2) Resource and Environmental Management Goals and Objectives

Resource and environmental management goals for watershed systems must, in some sense, be concordant--be harmonious and be rules for maintaining harmonious relations--with such natural-cultural systems. To achieve this, the goals and objectives must themselves be hierarchically ordered so as to conform with the national, regional, and local natural-cultural systems of concern. This is to say that national goals and objectives must be general enough that regional and local goals

and objectives, can be appropriate to regional and local natural and cultural capacities and conditions and at the same time remain consistent with the national ones.

At each level of organization of the natural-cultural system, the goal of a rationale ought to be to maintain the persistence of that system, and thus the hierarchy as a whole, in a series of states judged good in terms of humanistic understanding. The states themselves will be in constant flux with environmental perturbation of all kinds. This is not a matter of great moment. Maintenance of the fundamental capacities of these systems is the matter of primary concern. Thus, for example, we ought not be too concerned about the temporary states of stream systems in watersheds, for they will change for both natural and cultural reasons. Our concern is that the biological and physical capacities of these stream systems be maintained so that, over some time frame, each stream and some streams will be in the states desired, this being so for other streams in other time frames.

We must be concerned not simply with aesthetic environmental needs of man but also with his physical and biological needs. For these are not independent, either in man or in the natural cultural systems of which he is a part. All kinds of needs must be provided for in the system of goals and objectives, and explicitly so, for consistency among these must be achieved. Beyond this, the goals and objectives must be externally adequate. This is to say, if methods could be found to achieve such goals and objectives, the natural-cultural system of concern would then be provided for. And, of course, goals and objectives must take into account methodological possibilities, although the latter should never be narrowly conceived.

### (3) Classification of Natural-Cultural Systems

The only sort of classification that can begin to provide for scientific and environmental management needs of watershed concern will be a hierarchical one in which natural systems at the various level of organization are classified according to their capacities and their environments, their present states being primarily "inventory" interest. This is because such systems are apparently hierarchically incorporated and because their performances are far too variant over the time scales of interest to provide a reliable basis for classification. Moreover, it is their capacity that is of the most fundamental resource and environmental management concern.

The form of the classification system developed in Chapters 5, 6, and 7 is of this sort. Watersheds would be classified according to their capacities and their environments. But the environment of a watershed is its biogeoclimatic zone which would be classified according to its own capacity and environment, which is the biogeoclimatic region, to be similarly classified. Stream systems would be classified by their watershed class (their environment), by their order, and by their morphological capacity. Stream biological communities would be assumed to conform to the physical capacities and states of stream systems, so long as the biological capacities of the watershed are maintained.

Because cultural systems are broadly determined by the capacities and states of the regions and zones in which they developed, there will be general conformity between classes of natural systems and classes of cultural systems. But in a secondary way, cultural systems determine the states and may even affect the capacities of natural systems. In the sort of hierarchical classification here proposed, both natural and cultural systems would be combined at the watershed, zonal, and regional levels of organization. Such a scheme is not only a scientific and management convenience but, more importantly, comes near to the way things are and thus tends to insure that phenomenal understanding will be appropriately applied in attempts to achieve humanistic understanding locally and regionally as well as nationally.

#### (4) Resource and Environmental Management Criteria

For each of the various watershed classes of the United States, there will need to be assembled scientific knowledge of the relations between watershed practices, resource yields, and watershed and stream system conditions. We say "assembled" because much is already known and simply requires ordering along with the results of research intended to fill important gaps in our knowledge. Such knowledge must come to be specific for each watershed class. And a variety of watershed practices must be related to their particular outcomes in resource yield and system conditions. Indeed, particular practices on particular watershed classes should be evaluated under different environmental conditions. An entire set of relations between watershed practices and their outcomes for each class of watershed would be a set of watershed management criteria. Such criteria provide only the scientific basis for selection of the standards and best management practices to be instituted and enforced. This is because social and political considerations need to be taken into account in establishing standards and practices, and a clear distinction should be made between the necessary scientific and the necessary social parts of the judgments entering into watershed management (Warren, 1971). From among management practices leading to scientifically known effects--from among the criteria--there can be selected "best management practices" on the basis of social considerations.

#### (5) Resource and Environmental Management Standards and Practices

The best management practices selected from among the scientifically established set of criteria would not necessarily be those providing the highest resource yields or the most favored stream conditions. Given that a reasonably adequate scientific basis in criteria including knowledge of natural-cultural system capacities will one day be established, it is to be hoped that selection of best management practices will be based on rational national, regional, and local goals and objectives for each class of watershed. We say "rational" goals and objectives with the intent of relating them back to all the criteria of rationality considered in previous sections. It is not simply the highest yield, the most favored stream conditions, or any other particular performance of a watershed system that can be rationally defended. Rather, it is the indefinite persistence of a natural-cultural system in a series of good and beautiful states that is



the national goal of watershed management. Resource yield has something to do with this; so also do favored stream conditions; but there is much more; indeed, there are all considerations, the most fundamental of which is maintenance of all system and subsystem capacities, whether or not particular states are always the most desired.

Stream system "standards" should be written primarily in terms of stream system capacities, although some of these may need to be indicated by ranges of states. And these capacities and states should be primarily those of streambed and bank morphology, for so long as the stream biotic capacity of a watershed and zone are maintained--as they should be--the biological communities of particular streams will, over the important time frames, conform to stream morphology. Now such "stream standards" are not standards to be enforced in the usual way. Presumably it will be "best management practices" that are to be enforced, the stream standards being more nearly "objectives" of the management practices. For were the practices to be followed and the streams to fail to meet standards, legal action could hardly be justified. Rather, a change in the practices to be enforced would be indicated, so long as the intention was to achieve those stream standards.

#### (6) Administrative Institutions, Procedures, and Guidelines

Administration of what amounts to a national system of land management must be among the most ambitious, difficult, and problematical of governmental efforts. Although such a program can be rational in its own right, it is not at all clear that the limited goal of control of "nonpoint-source" pollution is the most rational basis for undertaking such a program or that there is the phenomenal and humanistic understanding to make it successful. On the other hand, it may be an opportunity to introduce some necessary correction into broadly irrational domains of land use.

However this may be, it would seem that administrative institutions, procedures, and guidelines must be extremely sensitive to whatever phenomenal and humanistic understanding may be available. Only in this way can the dangers of governmental arrogance and error be minimized.

In these matters, it is important that administrative institutions, procedures, and guidelines be organized along the same hierarchical lines as the classification would order the biogeoclimatic regions, zones, and watersheds of the country. This will help to make the national program sensitive and responsive to differences in the capacities and needs of the various regional and local natural-cultural systems.

#### (7) Evaluation of Conformity of Management Outcomes with Objectives

Certainly it is important that one of the outcomes of management be conformity of stream systems to stream "standards" or objectives, stream systems being the initial reason for this entire governmental activity. Monitoring of streambed morphological capacities and states should prove to be the most adequate means of such evaluation. But, as we noted above in section 2, goals and objectives for watershed system



and subsystem capacities and performances must be entirely interrelated and consistent, for we are dealing with what we must suppose to be naturally integrated systems. Objectives for the capacities and performances of stream systems must be consistent with objectives for the capacities and performances of timber and agricultural production. Stream regulation of this sort necessarily involves the Environmental Protection Agency in the management of impinging natural resources, for which some responsibility must then be assumed. Thus, evaluation of conformity of management outcomes with objectives must be across the entire spectrum of private as well as public concern.

#### (8) Correction of Objectives, Institutions, Standards and Practices

There must always be concern that our objectives, institutions, standards, and procedures may in some way be inadequate to the social task. Indeed there always is such concern, some of which is well-founded. The problem is in providing the means by which well-founded concern can play its appropriate social role. The issues are complex, so complex as to be fully grasped by few if any, even of those most deeply involved. There is the need in a rationale to provide explicitly for an informed public. Such informing should not be institutionally self-serving, as it usually is, but rather should serve to provide a critical and well informed public capable of evaluating not only public goals, objectives, standards, and practices but also institutions as well. But this in itself will be without purpose, short of revolution, unless means are also provided to make institutions sensitive and responsive to their critical and informed public.

#### DEVELOPMENT, EVALUATION, AND INSTITUTION OF A RATIONALE FOR WATERSHED MANAGEMENT

What we have been calling a rationale is clearly but the form of a rationale for watershed management: its substance is lacking. While much research is needed, much new knowledge will be slow in coming; for many years it will represent at best a small part of what is now known about watershed and stream systems. Even so, it may help to fill critical gaps in our understanding.

The core of the rationale here presented has been a classification system. It is hard, at least for us, to conceive of a rationale for watershed management on a national scale that would not be based on an adequate classification of regions, zones, and watersheds. Now, more than anything else, work should proceed toward such an adequate classification, perhaps one having a form something like we have here considered. Such a classification should order what already amounts to a vast empirical experience in the science and management of watersheds. If, once properly ordered, this experience is not nearly adequate for rational watershed management, we are then very many years from such management. We, at least, do not believe this to be so. But, the ordering of experience with an adequate system of classification cannot wait long.

The intensive development of alternative rationales for watershed management should begin immediately. The effort in doing so and in making choices from among them will help prepare all concerned for institution of rational watershed management in the near future. When this does come, rapid improvement in the capacities and states of the natural-cultural system of concern is not to be expected. What must be expected is a change in trends too long in wrong directions.

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